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CONDENSATION IN MANUFACTURED HOUSING

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CONDENSATION IN MANUFACTURED HOUSING

February, 1987

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Tang G. Lee, MRAIC
Principal Investigator.

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EXECUTIVE SUMMARY

BACKGROUND

This report discusses the issue of condensation in mobile homes. Although mobile homes provide economical and acceptable housing to many Albertans, the industry has been bothered in recent years by an unacceptably high incidence of interior surface condensation during the colder winter months.

The Manufactured Housing Association of Alberta was concerned about this issue and asked the then Department of Housing assistance in addressing this problem. The Department, now a Division of Alberta Municipal Affairs commissioned the author, Professor Tang G. Lee of The University of Calgary, to investigate, analyze and report on condensation in mobile homes. This report documents the work, findings and recommendations arising from that investigation.

The Department of Municipal Affairs established an industry advisory committee comprised of consumers, retailers, regulators, and manufacturers to assist in the management of the study. The committee was instrumental in drafting the project terms of reference and provided a frame of reference for the study which outlined an appropriate scope for the investigation and focus for the analysis. Further, the committee members were able to offer guidance to the author by providing valuable insights into the history and nature of mobile home occupancy and assistance in conducting surveys and field investigations.

OBJECTIVES

Whereas no previous studies had identified the scale of nature of mobile home condensation, the first project objective was:

i) to verify that a problem existed.

It was recognized that any proposed major remedial measures could require a significant time or expenditure to implement; therefore remedial objectives were broken into short-term and long-term recommendations:

ii) to propose short-term responses which can minimize the existing problem; and

iii) to propose retrofit procedures which can correct the existing problem.

Finally, in order to effect changes that would minimize condenstion in future mobile homes, the author was tasked with a fourth project objective:

iv) to propose new techniques or designs which can prevent the recurrence of condensation problems in new units.

METHODOLOGY

The study was broken into three phases: investigation, analysis and recommendations.

The invetigative phase was further subdivided into four activities: literature search, survey, interviews, and field study. Due to the limited literature available concerning mobile home condensation, the author also reviewed extensive works on condensation in wood framed structures with particular emphasis on small residential construction. In the survey phase the author received questionnaire responses from 65 homes. The sample was not statistically representative but responses were sufficiently uniform to suggest that it was fairly representative of the mobile housing norm.

The field investigations disclosed that most of the units which suffered from condensation build-up also suffered from a lack of proper ventilation. It became obvious that the more tightly sealed, non-vented units with re-circulating kitchen fans, and broken or unused bathroom exhausts exhibited some of the worst condensation problems.

The author provides an in-depth analysis of his findings along with a detailed explanation of the dynamics of condenstion in order to afford the reader an opportunity to properly evaluate the findings and field observations from their own perspective.

CONCLUSION

The author concludes that condensation, although a significant aesthetic and construction problem, can be readily reduced or eliminated by modest and cost effective interventions. The report summarizes these interventions in three categories:

i) lifestyle and maintenance activities to reduce moisture generation and improve its venting,

ii) remedial construction activities or adjustments to mechanical equipment which will improve envelope performance or enhance the exhausting of moist air, and

iii) changes in the design construction or siting of new units to reduce thermal bridging, improve air circulation and temper adverse site conditions.

The points described within the report for the above categories include the following items:

i) Lifestyle and Maintenance

1. Remove or disconnect any humidifying devices.

2. Do not hang clothes to dry indoors.
3. Do not leave bathtub and hottubs filled with water (if soaking clothes is necessary cover container with polyethylene or other material),
4. Ensure the clothes drier vent is not obstructed by snow or debris.
5. Clean the lint filter in the clothes drier regularly.
6. Clean the furnace filter regularly to ensure good air circulation.
7. Use the bathroom exhaust fans when bathing.
8. Use the kitchen hood fan (if vented) when cooking.
9. Open the windows for a short period when condensation becomes excessive.
10. Reduce the number of house plants.
11. If a water cistern is needed, use a lid and faucet.
12. Bring only a minimum amount of firewood into the house at any one time.

ii) Remedial Construction

1. Clear existing monitor vents of obstructions.
2. Reconnect and/or repair damaged clothes drier ducting and vent to outside, not to crawl space.
3. Clear obstructions from blocking clothes drier grilles.
4. Clear obstructions from window weep holes.
5. Replace broken windows.
6. Repair bathroom fan (if noise is still a deterrent to its use, replace with a quieter fan and use resilient mounts or install a dimmer to slow fan speed).
7. Replace kitchen recirculating fan with venting model.
8. Add an entrance vestibule for the purpose of keeping snow and mud from entering the house.
9. Slope grade around the house.
10. Provide a groundcover moisture barrier.
11. Replace roof mounted vents with stack vents which extend at least 600 mm above the roof.

iii) Design and Construction Changes

a) Manufacturing Plant Measures

1. Identify and eliminate any thermal bridging in the enclosure.
2. Ensure a good air-vapour retardant system throughout.
3. Avoid the use of ceiling mounted fixtures.
4. Continue the use of a gypsum board ceiling.
5. Drill weep holes in the sill and top plates.
6. Install only venting kitchen exhaust hoods.
7. Install a quiet bathroom exhaust fan.
8. Position the clothes drier on exterior wall.
9. Have factory installed clothes drier ducts and grille equipped with backdraft dampers.
10. Insulate clothes drier ducts if in crawl space and slope towards exterior.
11. Position any venting grilles as high as possible to avoid obstruction by snow and debris.
12. Retain monitor vents located near the entry.
13. Install a differential thermostat to circulate air throughout the home using the furnace fan.
14. Use only roof ventilators that extend at least 600 mm above the roof.
15. Use a pitched roof and full attic ventilation.
16. Use hermetically sealed windows and thermal broken frames.
17. Consider the use of triple glazed windows where excess moisture is expected.

b) On-Site Measures

1. Ensure crawl spaces are adequately vented.
2. Require that dealers inform mobile home purchasers of the causes and cures for condensation.

3. Slope grade away from the house.
4. Install ground cover in the crawl space.
5. Ensure skirting is maintained to prevent entry of animals and continues to vent the crawl space.
6. Provide adequate roof rain gutters and downspouts to prevent rainwater from entering the house.

1.0 INTRODUCTION

1.1 BACKGROUND

Mobile homes currently play a significant role in satisfying the housing requirements of many Albertans. This is particularly true in many rural and northern communities. In recent years, the mobile home manufacturers have responded to consumer demands to build units which incorporate the latest in wall technologies, materials, and energy efficiency. Despite or possibly because of these efforts, a number of the newer homes have exhibited an unacceptable incidence and level of surface condensation and resultant envelope deterioration.

In response to these condensation concerns, the joint government-industry Manufactured Housing Advisory Council established a sub-committee to consider the issue. The sub-committee sought support from the Housing Division of the Alberta Department of Municipal Affairs. Because of its mandate to assist the housing industry and because of its own extensive mobile home holdings, the Department agreed to assist in the review of these condensation matters and to that end engage the author, Professor Tang G. Lee of the Faculty of Environmental Design at The University of Calgary, to investigate the subject.

1.2 OBJECTIVES

The purposes of this study were to investigate condensation related problems in manufactured housing, to propose solutions to the problem in existing units, and to propose techniques to prevent the problem arising in new units. The detailed objectives were to:

1) verify the condensation problems and investigate their causes;

2) propose short-term responses which can minimize the existing problem;

3) propose retrofit procedures which can correct the existing problem; and

4) propose new techniques or designs which can prevent the recurrence of condensation problems in new units.

1.3 SCOPE AND FOCUS

The range of units to be studied and the number of topics to be considered were determined by the sub-committee. Based on their experience with homes in the field, the committee members proposed the following terms to establish the study scope:

1. manufactured homes with interior condensation and high relative humidity;

2. moisture induced envelope deterioration and structural damage;

3. manufactured homes built under C.S.A. standard Z240 since September 1978; and

4. manufactured homes located primarily in northern Alberta.

Specifically excluded from this study were the following issues:

1. health problems arising from poor air quality;

2. other environmental air pollutants; and

3. water damage resulting from leaks or other sources not related to high interior relative humidity or condensation.

Further, the committee directed that the investigation should focus on those units which had reported condensation problems. However, the members were aware that units built since September 1984 under the new CSA Z240 standard were showing markedly improved performance; consequently, they also directed that a sample of these newest units should be included for assessment and comparison purposes.

1.4 APPROACH

Because it was not possible to find significant studies on condensation problems in Canadian mobile homes, this project included detailed survey work. A detailed research approach is outlined in Figure 1 on page 3A. The numbers beside each item are briefly explained in Appendix A.

The information relevant to this study was obtained from the following four major sources:

1) literature review,
2) collaboration,
3) questionnaire, and
4) field investigation.

1.4.1 Literature Review

Part of this report was based on much of the available published literature on the general problems of condensation in buildings. With respect to condensation problems in mobile homes however, the literature was extremely limited. Many of the symptoms, causes, and solutions to condensation are similar in site-built houses and mobile homes.

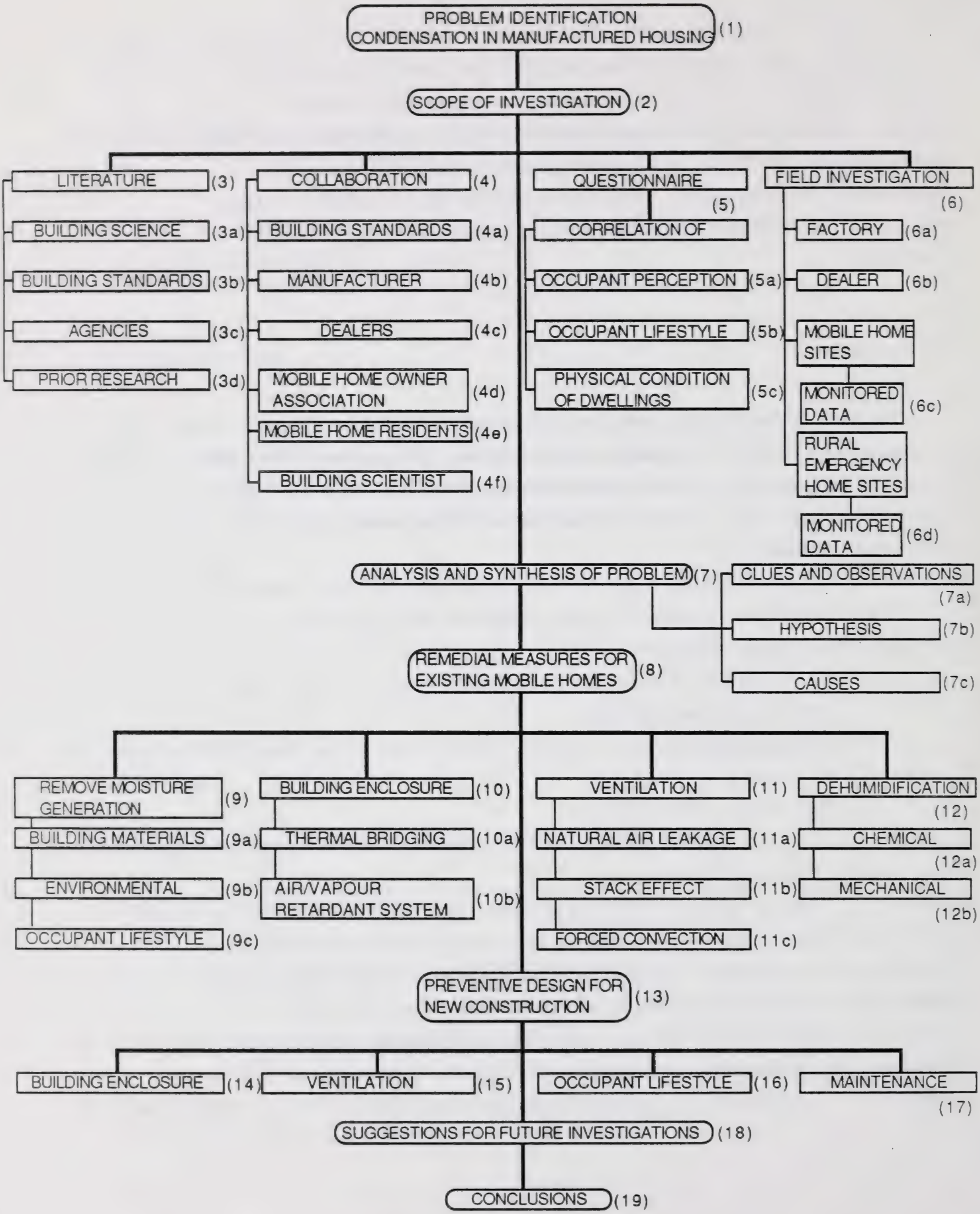


FIG. 1: Flowchart of investigative procedure

The literature reviewed included books pertaining to building regulations and standards, both for site-built and mobile homes. Changes to these standards indicate some recognition by the authorities of potential condensation problems. Some of these improvements include the requirement for an air-vapour retardant enclosure, the concern for thermal bridging, and the recommended standards for indoor air quality.

1.4.2 Collaboration

The lack of studies related directly to Canadian condensation in mobile homes necessitated obtaining information from other sources. We were able to approach many people in the manufactured housing industry since the results of this study had the potential to benefit their industry. Many of the manufacturers and dealers have a fairly good perception, understanding and experience with condensation in mobile homes. Most of them have made modifications to their product to mitigate the condensation problem. It would appear that as a result of the introduction of the new Z240 standards which require 0.5 air changes per hour, there has been a reduction in the demand for dealer's servicing of condensation problems. The introduction of fresh air into mobile homes reduces condensation problems by exhausting any build up of moisture. The emphasis on consumer awareness regarding the causes and simple cures for excessive condensation problems in houses was also a contributing factor. It is for these reasons our project included extensive discussion with people and relevant authorities with backgrounds in mobile homes. In addition, the assistance and feedback from individuals in the Alberta Manufactured Housing Advisory Committee and those belonging to the Mobile Home Owners of Alberta proved invaluable.

1.4.3 Questionnaire

Residents of mobile homes were also contacted to obtain their comments about condensation, and their experiences living in a home with such problems. A resident survey, summarized in Appendix B, was also conducted to obtain some general information on the topic. Results of the questionnaire are incorporated throughout this report.

Of the sixty-five people who responded to the questionnaire, only three indicated no condensation problems. This limited survey cannot be regarded as accurately quantifying the extent of condensation problems in northern Alberta. Nevertheless this survey does indicate there are obvious misconceptions about condensation and its cures. For example, the questionnaires indicate only half of the mobile homes have monitor vents. Of those which have such vents, only a quarter knew what they were for. More revealing was the significant minority of the mobile home residents who use humidifiers; approximately 30% of which expel up to one gallon of water per day into the air of the mobile homes.

The questionnaire also revealed that most (61%) mobile homes have recirculating exhaust hoods above the kitchen range. Those which don't have kitchen exhausts discharging to the outside have greater condensation problems.

1.4.4 Field Investigation

Regardless of the many sources of information addressing building condensation, field investigation was an essential part of the research. First-hand knowledge can result in insights not readily obtainable from the literature or from other people's experiences. In addition, field investigation may uncover important clues not observed, considered unimportant, or absent in the field investigation by other researchers.

In this project, a field investigation addressing the problems of condensation in mobile homes in northern Alberta has been undertaken. The week of February 17th, 1986 was spent in northern Alberta, from Edmonton to the Peace River region. Local authorities and residents of these mobile homes were contacted to gather specific information on the extent and nature of condensation problems. In addition conditions affecting condensation and/or evidence of such occurrences in the past were observed, examined and monitored. The purpose of the field investigation was to clarify, refute and/or verify existing hypotheses, and uncover unanticipated clues, symptoms, causes or solutions to condensation problems in mobile homes.

The field investigation methodology is listed below.

a) Extended interviews with selected mobile home residents to

- establish the manufacturer and history of the unit,
- determine the long-term symptoms of condensation,
- determine a correlation between the occurrence and severity of condensation and climatic changes, occupant life styles, etc.
- establish history of physiological indications of dry indoor air, and
- supplement data collected in the original survey questionnaire.

b) Visual observations of existing physical conditions to

- observe condition of ground moisture barrier, rain runoff, and venting of crawl spaces,
- record visual evidence of condensation in occupied units,
- record existing conditions of the units in terms of orientation,
- record extent of moisture generating sources,
- record conditions of building components such as windows, doors, furnaces, etc., and
- determine the quality of workmanship, materials and components.

c) Recording of environmental conditions to

- establish the environmental conditions such as air temperatures, wind velocity, relative humidities in and around the units,
- record at least a one day continuous temperature and relative humidity cycle in an occupied unit, and
- record the rate of water vapour dissipation after a shower, with and without the doors closed and with and without the use of the bathroom exhaust fan.

d) Measuring existing conditions and performance of the building enclosure to

- record wall, floor and ceiling surface temperatures,
- locate areas of thermal bridging and cold spots,
- identify, locate and measure the extent of air leakages through the building envelope,
- determine the condition of the weatherstripping seals, and
- determine the thermal and air leakage performance of the building enclosure.

e) Measuring the existing conditions and estimate performance of mechanical units to

- determine the approximate effectiveness of the heating system, and
- determine the operating conditions and discharge locations of the bathroom, clothes dryer and kitchen vents.

f) Internal inspection of the building enclosure to

- determine the extent of moisture and frost accumulation within the building enclosure,
- determine the moisture content of the various building

materials, obtain samples for laboratory analysis,

- determine the quality of construction and the materials used,
- determine if any movements of the building have affected the integrity of the building enclosure,
- determine the condition of the air/vapour retardant system, especially at the ceiling where penetrated by services, chimney and other components,
- examine the attic and chimney flues for evidence of condensation and air tightness,
- examine the ability of the roof to ventilate, and
- determine if the floor ducting is adequately insulated, and air tight.

1.5 REPORT ORGANIZATION

The report is organized in four parts. PART I - "IDENTIFYING THE ISSUES" is further sub-divided into the following three sections:

Chapter	2.0	Condensation in Mobile Homes - outlines the broad topic of condensation and by comparison to the widely understood conventional residence explains the properties and problems which make mobile homes a unique subject for review.
	3.0	Properties of Water Vapour in Air - details the physics and dynamics of water vapour and air movement which the reader will require in order to understand the building science approach that the author has adopted to explain residential condensation.
	4.0	Energy Conservation and Air Quality - explores the interrelationship of the home heating and ventilating systems in controlling condensation and how these systems also affect the general air quality.

PART II - "FINDINGS" constitutes one half of the main body of the report and is comprised of four sections:

5.0 Sources of Moisture - details the external and lifestyle activities which introduce moisture into the home.

6.0 Water Vapour and Building Materials - outlines the primary and secondary effects water can have on the materials and finishes in a residence.

7.0 Visible Condensation - discusses the aesthetic, and deteriorating effects of standing moisture.

8.0 Concealed Condensation - details the problems which can arise from the unseen and often forgotten condensation which occurs within the building envelope; deterioration of the structural system, lowering of insulation values, or the collapse of mechanical and electrical systems.

PART III "REMEDIAL MEASURES AND PREVENTATIVE DESIGN" deals with the solutions to condensation in five sections:

9.0 Retarding the Flow of Air and Water Vapour - looks at systems and materials which prevent moisture from penetrating the building envelope and condensing on cold inaccessible surfaces.

10.0 Removal of Air From the Attic - discusses corrective measures which can eliminate moisture and reduce its deteriorating effects once it has penetrated the ceiling membrane.

11.0 Removal of Moisture From Walls - explains corrective measures which can be utilized if the walls have already been subjected to condensation and still suffer from wetting.

12.0 Reduction of Indoor Moisture Levels - outlines strategies and products whose use will minimize the moisture content of the indoor air thus lessening the chance for surface condensation.

13.0 Ventilation - discusses the role of the mechanical system in maintaining a balance of fresh air within the home and the subsequent control of moisture build-up and condensation.

PART IV "CONCLUSIONS" - summarizes the remedial measures outlined above and groups them in terms of short-term responses, remedial retrofit solutions and design or construction proposals for new units and site placement.

The report concludes with detailed references and bibliography, an itemized outline of the investigative procedures, and the questionnaire form and numerical responses.

PART I IDENTIFYING THE ISSUES

2.0 CONDENSATION IN MOBILE HOMES

Condensation is a problem that is common to all buildings that attempt to maintain a warm internal environment during our frigid Canadian winters. The problem is amplified in residential buildings. Residential building envelopes tend to employ the least sophisticated of our building technologies despite the fact that resident lifestyles and health needs result in the highest levels of condensation producing humidity. Our housing industry has generally resolved this problem in our conventional housing stock; however, mobile homes exhibit a number of unique differences and problems. This section explores those differences and provides a background for understanding the problem of condensation in mobile homes.

The manufactured housing industry serves an important role in providing affordable housing to a certain percentage of the population. It originally had the advantage of cheaper sale prices as the mobile homes did not have to fully comply with the building code and were built on minimal subdivisions. As with moveable trailer type units, the fixed mobile home could provide rooms and corridors to any practical size, although sometimes below the minimum standards recommended. Materials used were often lighter and cheaper than those in conventional houses, and the foundations were not required to be below grade.

By contrast today's mobile homes have evolved to the point where they comply to the National Building Code and are of the same quality as conventional site-built houses. Even the required thermal insulation values are the same as conventional houses, but the important price advantage is maintained. Much of the savings in mobile homes is attributed to the economy and efficiency of factory building conditions, the extensive use of pile foundations and crawl spaces, and sometimes less stringent subdivision planning requirements. The contemporary mobile home is not necessarily of lower quality than site-built houses. Indeed, some well designed and well built mobile homes are considered, especially by the mobile home owners, to be of better quality than some site-built houses (1).

Lifestyles and family compositions of mobile home residents do not differ from those living in site-built houses. The activities of a typical family of four would be similar in both types of dwellings. Each will cook, wash, sleep and use the home in similar fashion. Consequently, the moisture generated by such activities of the same size family in both types of dwellings are the same. However, the likelihood of condensation and the associated problems is greater in mobile homes than site-built houses.

Manufactured houses have unique conditions, compared to conventional site-built houses, that make them particularly susceptible to the formation of condensation; the unique differences being as follows:

a) smaller volume,
b) less materials to absorb interior moisture,
c) more cold surfaces due to thermal bridging,.and
d) furnaces which do not draw air out of the house (as discussed in chapter 4).

The site-built house is generally larger, often doubling as a result of a full basement. The volume of air inside the house has a direct relationship to its capacity to dissipate and contain moisture. The smaller volume of air inside a mobile home will become saturated with moisture earlier than the larger volume of a site-built house. Furthermore, because the site-built house is larger, it has more materials to absorb moisture during periods of high humidity, and to slowly release the moisture during periods of low humidity. This phenomena is akin to the flywheel effect or the time delay it takes to cool a rock after heating. In addition, the indoor humidity in the site-built house is often drier as a result of greater air leakage from the larger surface area of the enclosure.

The third difference between the mobile home and the site-built house is less apparent as the quality of mobile homes increases. In general, however, a percentage of old mobile homes were built to lower standards than was the case with site-built houses. While the minimum level of thermal insulation is identical in both types of houses, some building components are thermally less efficient in mobile homes. For example, cheaper windows were generally installed in older mobile homes. The individual glass pane slider type windows and aluminum frames without thermal breaks were often installed in earlier, pre-1976, mobile homes. The thermal conductivity of aluminum is 800 to 1400 times that of wood (2). The result is a colder window frame and sash which will likely result in condensation at lower humidities. Fortunately newer mobile homes use hermetically sealed glass affixed to thermally broken sash and frames.

Another area of thermal bridging in a mobile home is located at the wall and ceiling junction where condensation is generally most noticeable. The double top plates, and the reduction in depth of insulation necessary to maintain a venting space in the attic increases the thermal conductivity in this location (see Figure 2 on page 13A). Although it is not a code requirement, many site-built houses have already incorporated raised eaves in order to increase the amount of insulation, but many mobile home manufacturers are unable to include this added feature for reasons of travel height restrictions. Our survey shows many of the ceilings and roof junctions of older mobile homes are colder, resulting in condensation damage such as staining of the ceiling.

With respect to the ceiling drywall extending across the top plates, one mobile home manufacturer believes this feature will act as a gasket or seal between the wall and ceiling. Furthermore, this practice accommodates the factory assembly process in the manufactured housing industry. The roofs of mobile homes are made on a jig and the entire assembly is placed into position on top of the home. Any inaccuracies between the roof and the walls would leave a

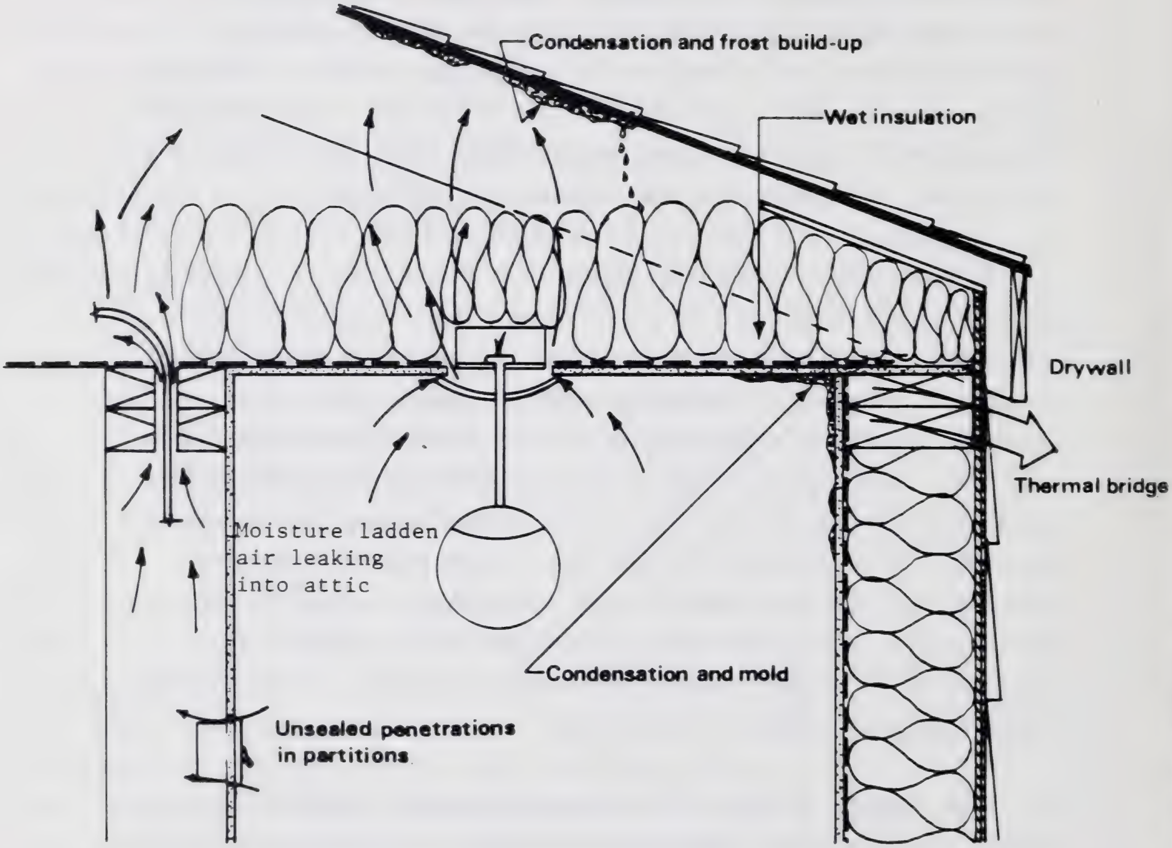

Condensation and frost build-up
Wet insulation
Drywall
Thermal bridge
Moisture ladden air leaking into attic
Condensation and mold
Unsealed penetrations in partitions

FIG. 2: Air leakage and thermal bridging in ceiling

gap at the ceiling to wall junction. It may be advisable to reconsider the continued practice of extending the ceiling drywall over the exterior wall double plates. This configuration acts as a thermal bridge; the thermal conductivity of drywall is one third greater than wood. In this investigation, the wall and ceiling junctions exhibit some of the first signs of condensation and mold formation. However, on balance, the added costs and reduction in travel strength may not justify the potential marginal improvement, particularly in light of the new ventilation requirements and prevailing use of 38 x 140 (2" x 6") wall construction.

Among the types of buildings having major condensation problems in Canada are high humidity buildings such as swimming pools (3) and ice arenas (4,5). In addition, there are a number of studies on moisture related problems in residences which are referenced throughout this report. However, condensation problems in mobile homes have not been well documented. Discussions with the mobile home industry indicate a lack of such studies:

a) Mobile homes until the early 1980's were built to fairly relaxed air tightness standards. As a result, the air leakage had a dehumidifying effect on the amount of moisture that could accumulate inside the mobile home.

b) The manufacturers of mobile homes in Canada generally do not have the economic means to retain building science consultants to conduct condensation studies on their product lines.

c) Many residents of mobile homes (and site-built homes) consider condensation to be a nuisance that must be tolerated during the winter. Lack of knowledge about condensation and its prevention also reinforces this defeatist attitude. Many residents merely mop up the condensation rather than seek a more permanent solution.

Our survey and interviews indicate the condensation problem is no longer being tolerated:

a) The severity of condensation has increased in mobile homes due to upgrading of energy conservation standards including improved air tight construction. The interior moisture levels increase significantly from the lack of ventilation. The nuisance became intolerable as the amount of condensation and the resulting mopping of water became too frequent and the damage too severe.

b) Some home purchasers choose mobile homes even though they have the financial means to acquire site-built homes. A reason for living in mobile homes is its reduced maintenance. With the increasing condensation problem, mobile homes are no longer maintenance free. Consequently owners are demanding satisfaction from the dealers and manufacturers.

c) There is an increase in the number of publicly owned mobile homes such as those owned by the Province of Alberta. The economic consequence of premature deterioration of these large housing stocks is substantial. The cost of conducting a study on the causes of condensation and its remedial measures is now acceptable because that cost is spread over a large number of homes.

In summary, high humidity levels and the resulting condensation can be detrimental to the function and service life of any building. Because of the difference between mobile homes and site-built houses, the formation of condensation results in an unacceptable rate of building deterioration. The consumer and the manufactured housing industry have a mutual interest in reducing premature damage of mobile homes due to condensation.

3.0 PROPERTIES OF WATER VAPOUR IN AIR

In order to understand condensation, one must understand a host of interrelated environmental and building science issues. At its simplest level, condensation may be said to occur when moist air meets a cool surface. In reality, condensation and the resultant damage to the building envelope are the products of a complex interaction of environmental air and moisture dynamics within the enclosing structure. This section explains those environmental dynamics within the building envelope and provides a background which will assist the reader to understand the following section regarding findings and recommendations.

3.1 Function of the Building Enclosure

The overall function of the building enclosure is to selectively separate the indoor and outdoor environments so that the indoor environment can be adjusted and maintained within acceptable limits. In certain circumstances the occupants can decide to open the enclosure to allow air, light, and people to pass through. With respect to flows of water, heat, sound and moisture, it may be desirable to retard, if not completely restrict, such exchanges. The purpose of the building enclosure therefore is to maintain a comfortable level indoors, despite the variations of outside climatic forces outside. In addition, the enclosure must be durable and aesthetically pleasing.

3.2 Water Vapour and its Effect on Buildings

The presence of water and water vapour in the building enclosure is the most damaging of all natural forces (other than natural calamities such as floods and earthquakes) (6). Water and moisture will cause rot, rust or other deterioration in building materials. Standing water can become a health problem by providing a fertile environment for breeding bacteria. If water could be eliminated from contacting such building materials, many problems could be avoided. Since it is not possible to eliminate water from the environment, it is necessary to cope with water by recognizing its various sources, controlling its movement, and keeping the quantity of water in contact with the building enclosure within tolerable limits.

One of the principal sources of water concern in buildings is water vapour. Water vapour is a colourless, odourless gas and is universally present in the air. It is beneficial to the occupants and generally harmless to building materials. In contact with cold surfaces, however, water can condense out of the water vapour, wetting such surfaces. The results of condensation can be as minor as impaired vision through windows and dust markings on cold surfaces, as major as an electrical short-circuiting, or reduction in the service life of building components. Unless the cold surface is made of a material such as glass that can withstand water, the water can dissolve solids, cause materials to expand, accelerate the deterioration process, and increase the thermal conductivity of insulating materials. Furthermore, if the surface is below freezing, the condensed vapour can turn to frost or ice, expanding during this change, and possibly exerting sufficient force to separate materials. Therefore, condensation must be controlled to maintain an optimum indoor environment and to extend the performance and service life of the building enclosure.

Figure 3 on the next page illustrates the water vapour exchanges across the building enclosure. Vapour always migrates from areas of higher humidity to areas of lower (drier) humidity. Rising dampness from the ground adds considerable moisture to the atmosphere above. In a house with a crawl space, such as a mobile home, rising dampness will increase the humidity in the crawl space. Water vapour will migrate into the house above unless the floor is adequately sealed.

Similarly moisture from the house will migrate into the roof cavity (space between the top of the ceiling insulation and the

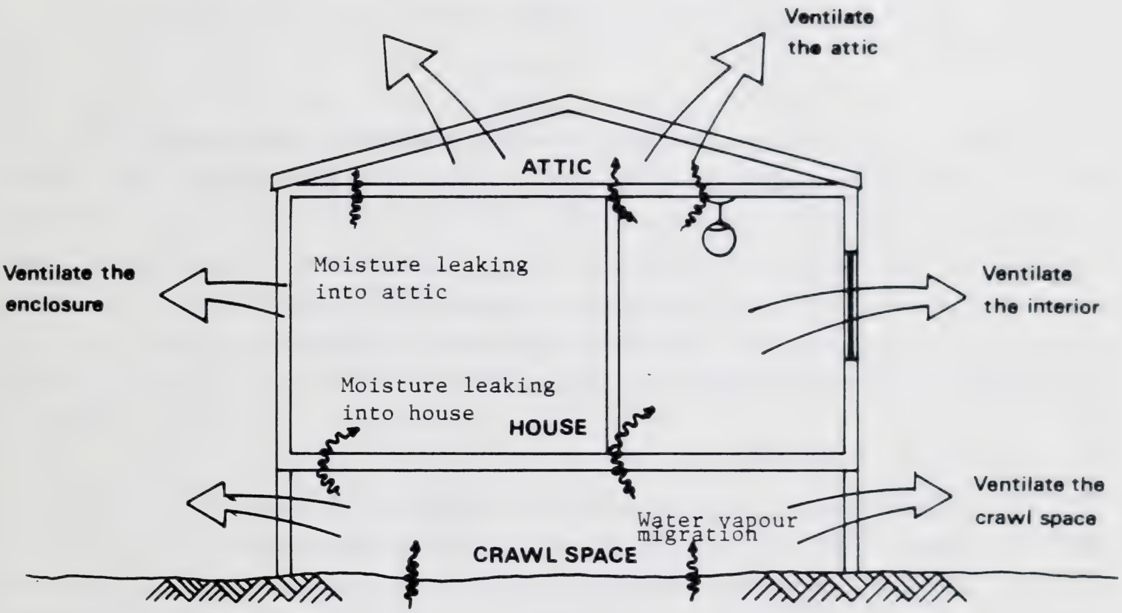


FIG. 3 Moisture migration and ventilation in a mobile home

underside of the roof) through any openings such as cracks and joints in the ceiling. If the roof cavity accumulates too much moisture, condensation and frost will form on the roof structure. During a warm period, the frost will melt, wetting the structure and ceiling insulation. To minimize the amount of water vapour from migrating through the enclosure requires careful detailing and construction. It is difficult, however, to achieve a perfect air and vapour seal between the house and the ceiling. To minimize the build up of condensation and frost, the roof cavity must exhaust excess moisture to the outside.

There is also a vapour pressure difference across the exterior walls resulting from higher moisture levels indoors. Water vapour that migrates through the wall during the winter will form condensation and frost inside the wall. Again the solution is to construct as good an air and vapour retarding system as possible in the wall. In addition, any small amount of moisture in the wall must be allowed to dry out by venting to the outside.

In January of 1960 the Division of Building Research at the National Research Council of Canada launched its first Canadian Building Digest (CBD) article. These articles were intended to provide important information to those who must deal with the technical and related aspects of buildings. It is appropriate, and indicative of the importance of water vapour, that the inaugural issue written by Neil B. Hutcheon, deals with the topic of humidity and its effects on Canadian buildings. This article describes the process by which vapour can condense into water and its deteriorating effects on the building structure. Unless the designer fully appreciates the influence of humidity on the building performance, it can become a serious problem (7).

In 1963, Hutcheon outlined eleven principal requirements of a wall, one of these being the control of water vapour flow (8). It is desirable to regulate the flow of water vapour to maintain a desired higher humidity level inside, and prevent formation of water resulting from condensation within the building structure. To control the migration of water vapour into the building enclosure, it is important to understand the nature of water vapour subjected to environmental conditions.

3.3 Principles of Psychrometry

The study of atmospheric conditions with respect to the mixture of air and moisture, is called psychrometry and includes such processes as condensation, relative humidity, dew points and so on. Within the normal range of temperatures and pressures experienced in Canada, water can exist as a gas, liquid, or solid. Condensation per se refers to the transition of water from the vapour to the liquid phase. The maximum amount of water vapour that the air can hold is governed by its temperature and pressure. The warmer the air, the more water vapour it can contain. When the air temperature falls below a certain level, a portion of the water vapour will condense into water. This level is termed its "dew point".

The dew point temperature however, is not constant but varies with the amount of water vapour in the air. The familiar psychrometric chart as seen in Figure 4 on page 19A offers a graphic representation of the manner in which temperature and water vapour content interact to produce a range of conditions for condensation (9). The "saturation line" represents that temperature at which the air is completely saturated with water vapour, representing 100% relative humidity. If the temperature drops below this, condensation will result. For example, if the indoor temperature is 22°C and a relative humidity of 50%, the dew point temperature is 11°C. Any surfaces such as a window or wall in the house which is 11°C or lower will exhibit condensation. If the surface temperature is below 0°C, the condensation will turn to frost.

Assuming the amount of moisture in the air is constant, a cooler

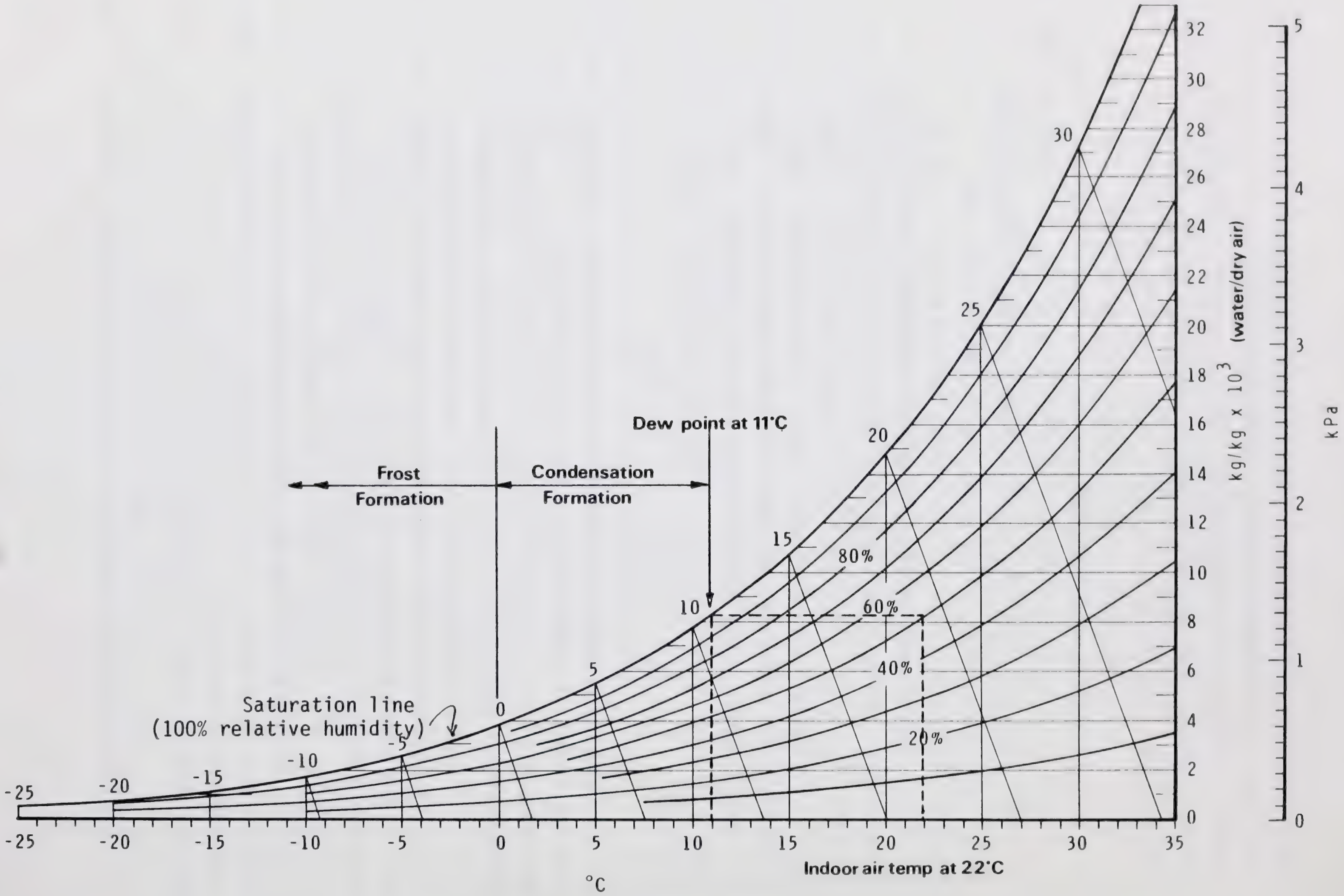


FIG. 4: Psychrometric chart

house will exhibit condensation before a warmer house. A cooler house will have cooler surfaces on the enclosure as less heat is conducted to the exterior. As a result, the dew point on these surfaces is reached earlier than in a warmer house.

Relative humidity is a measure of the amount of moisture in the air as compared to the amount that the air could potentially hold at that temperature and it is expressed as a percentage. The relative humidity in a building depends upon the amount of moisture in the air, the rate at which moisture is supplied to the air within the building, and the ventilation rate or the rate at which the moisture is lost from the building, and the moisture content of the outside air which is brought in to replace the exhausted air.

Water vapour content in the air can also be expressed in terms of its partial pressure. The atmosphere consists of a number of gaseous substances, each of which has its own partial pressure. The sum of these is referred to as the "barometric pressure". The partial pressure of the water vapour in the air is called the "vapour pressure". The ratio between the actual vapour pressure and the saturation vapour pressure - the vapour pressure at which the air is saturated - is another useful way to derive a measure of relative humidity.

3.4 Diffusion

Diffusion is the process by which water vapour migrates through a material. When a vapour pressure gradient exists, water vapour will attempt to equalize the imbalance through a process of diffusion. The direction of this movement is always from the area of high vapour pressure to the area of low vapour pressure. The rate of flow is directly proportional to the vapour pressure drop or difference, and inversely proportional to the vapour flow resistance of any material interrupting the flow.

The unit of measure adopted to describe the ability of a material to permit the diffusion of water vapour is the perm. It is defined as 2.01 x 10E-6 kg (0.00000201 kg) of water passing through one square metre of substance in one hour under influence of 1 kg/m^2 (pascal) pressure differential. The unit of permeability used to describe the ability to resist the flow of water vapour is the rep. It is the reciprocal of the perm. The permeance of individual materials can be found in the ASHRAE Handbook of Fundamentals (10). The overall water vapour resistance of an assembly in series is the sum of the vapour resistance offered by each material. This assumes conditions of unidirectional, steady state flow.

Given the vapour flow resistance values for each member of a wall, and the vapour pressure drop across the wall, it is possible to determine the rate of flow through it. This can be done using the relation that:

Equation #1.

$$\text{Vapour flow} = \frac{\text{Vapour pressure difference}}{\text{Vapour flow resistance}}$$

This relationship assumes that there is continuity of flow, that is, all of the water vapour that enters the building envelope on one side leaves through the other side. This is not always the case. If vapour should come into contact with a surface inside the enclosure where its temperature is below the air's dew point, condensation or freezing will occur. In effect, the vapour pressure of the air adjacent to this dew point plane will decrease due to the dehumidifying effect of the condensation process (11). Furthermore, the total vapour resistance of the assembly is altered from the steady state calculation as the condensed water or (if the condensation plane is below freezing) the frost will contribute its own vapour resistance. Finally, the water may never flow completely through the assembly as each material will absorb some of the water vapour as it passes through, thereby increasing its individual moisture content and altering its vapour resistance.

3.5 Air Leakage

It was originally thought that diffusion was the most influential mode of water vapour movement. However, it has been revealed that water vapour migration through air leakage is of much greater importance to the problem of interstitial condensation (12). This refers to the vapour which is transported with the air as it migrates through the building assembly. Since air flow is induced by differences in air pressure caused, for example, by stack effects and/or wind pressures, the direction of flow is always from an area of high air pressure to an area of low air pressure. The stack effect sometimes called the chimney effect, is dependent on the height of a heated building. In a mobile home of one storey, the natural stack effect is negligible but the induced stack effect of the gas fueled water heater or fireplace chimney can depressurize the inside thus creating an increased differential pressure.

Small openings and cracks in the exterior walls of a building are present due to dimensional instability of building materials when subjected to environmental changes, soil settlement, and joints. For example, there are gaps between electrical boxes or windows and their rough opening in the enclosure. These openings provide a route through which air can flow should an air pressure differential exist (13). The rate of flow is directly proportional to the drop in air pressure from one side to the other side of the enclosure. It is theoretically possible to calculate the rate of air flow for a building enclosure. As discussed earlier, the unpredictable nature of the environment makes such calculations of air leakage rates extremely difficult.

The leakage of air from within a building is called exfiltration while the flow into the building is called infiltration. With respect to condensation, exfiltration is of greater importance. This is because the air inside is usually warmer and has a higher moisture content due to moisture generated from perspiration and by normal household activities. The leakage of warm moist air through the building envelope, which becomes increasingly colder towards the outside, presents a potential problem. The resulting condensation, if of sufficient quantity within the building assembly, can lead to the deterioration of the building materials.

4.0 ENERGY CONSERVATION AND AIR QUALITY

Condensation can not be considered in isolation of a mobile home's heating or ventilation requirements. As noted previously, condensation is a product of the interaction of air, temperature and moisture in a home. Further, many of our condensation problems are the result of our constructing progressively tighter building envelopes in response to energy conservation needs. Consequently, this section explores the role that energy conservation initiatives and air quality concerns play in the understanding of condensation problems and the development of comprehensive solutions to those problems.

4.1 Building Energy Conservation

The move towards more energy conserving buildings has resulted in more air-tight building enclosures which can often result in a loss of air quality, and increase the likelihood of condensation problems. The full extent of these side effects were not anticipated nor were the consequences fully appreciated. Experiences with the problems of energy efficient houses warrant a re-evaluation of traditional design concepts, building components, mechanical systems, and construction procedures. For example, air tightness is achieved with the copious use of sealants and wrappings to provide air barriers and vapour retarders. This has resulted in new products such as Tyvek (14). The introduction of the heat recovery ventilator (HRV) was meant to solve the problem of air quality without high heat loss due to air change. Improving workmanship, using new sealants incorporating the HRV, and increasing thermal insulation (made possible by building thicker walls) increase the cost of a house by approximately $3,000.00 to $7,000.00 per unit. The typical house with a $700.00 annual heating fuel cost may only save $400.00 per year. The resulting payback period for constructing an energy efficient house could be well over ten years. Nevertheless, the advantages of increased comfort levels, some heating fuel savings, and the conservation of our natural energy resources may be sufficient reasons for the prospective home owner to purchase a house with such features.

Improvements in thermal performance of the building enclosure is achieved by more complete and careful fitting of building materials and components, and the installation of an air barrier materials such as caulking and weatherstripping. Considering that air leaks account for approximately 20 to 24% of the total heat demand in a typical house, plugging all air leaks is prudent (15).

Most houses today have electric powered fans to help extract heated air from the furnace and distribute it more effectively throughout the house. Such furnaces are 50% to 70% efficient depending on the age, model, manufacturer, operating conditions and regularity of maintenance. While furnaces with powered air handling features increase its distribution efficiency, they still lose much house air up the chimney.

Newer homes have furnaces that reach 75% to 95% efficiency. One of the techniques to increase overall furnace efficiency is the introduction of the automatic flue damper. The heated chimney flue creates a natural stack effect, drawing air out of the furnace and the house, but the automatic damper interrupts such losses between furnace operations. The result is a 10% to 15% improvement in overall furnace efficiency (16). As with draft-proofing the house, the automatic damper also reduces the natural ventilation of household odours and water vapour.

4.2 Air Quality

A minimum level of fresh air is needed for health maintenance and to satisfy furnace combustion needs (17). Fuel burning furnaces remove air from the house and discharge it up the chimneys, causing a slightly negative pressure inside. If too much air is removed, the negative pressure can reverse the natural flow of gases up the other chimneys such as those for hot water heaters and fireplaces, causing some of the fumes to mix with house air. Therefore, the risk of carbon monoxide (CO) poisoning or asphyxiation is increased.

Each year in Canada, about 10 people die and 100 people receive in-patient hospital treatment as a result of CO poisoning attributed to incomplete combustion of domestic fuels (18). There are many more incidents and treatments not handled by emergency departments, doctor's offices, police and fire services, or not serious enough to be reported. Tightly constructed energy efficient houses or smaller houses with less exterior surface areas through which air can leak, can aggravate the problem of inadequate fresh air to replenish chimney exhausts. The direct link of air-tight construction to gas levels is inconclusive, and CO poisoning is not widespread, but the problem does exist.

In general 30 litres of air is needed for each litre of gas burned in a furnace (equivalent to 2.4 L/s of combustion air per kW of gas burned). The Installation Code for Natural Gas Burning Appliances and Equipment, CGA B149.1-1976, section 6.2.1, of the Canadian Gas Association reads as follows (19):

> " When an appliance is located in an unconfined space within a building having insufficient infiltration, the air supply shall be obtained from outdoors and permanent openings, having a total free area of not less than (10 cm^2) per (2.25 kW) of total input rating of all appliances, shall be provided. "

Having satisfied fresh air requirements for combustion purposes and eliminated problems of CO poisoning in a house, we must also consider the control of oxygen levels, odours and other pollutants such as those emitted from furnishings, finishes, aerosols and household chemicals. Properties and tolerable limits of many air contaminants have been set out by ASHRAE (20).

The respiration rate for an inactive seated person is about 0.15 L/s. If the oxygen content is as low as 16%, and a carbon dioxide content as high as 0.5% is acceptable, a ventilation rate of 1.5 L/s per seated person is needed. Obviously the respiratory rate is related to metabolic rate or physical activity. The ASHRAE ventilation standard 62-1973 (21) set out minimum outdoor air requirements of 2.5 L/s (5 cfm) per person, and other sources recommend no less than 3.8 L/s (8 cfm) for odour control alone (22).

For a 100 m^2 dwelling with four occupants, the minimum ventilation rate required by the building code is one half air change per hour (ach). Concerns for building heat loss resulting from uncontrolled air leakage, duration of occupancy, the hazards to health posed by tobacco smoke, the increased use of man made materials, and body altering products, have complicated the issue of adequate indoor air quality. ASHRAE has allocated 30% of it operating funds to investigate this topic in 1986. Presently, 0.5 ach (60 L/s) in a typical size house seems to be accepted by a number of authorities on pollutant build-up (23). This is approximately three times higher ventilation than required for a typical four person family house with combustion air requirements. As we shall see later, the 0.5 ach ventilation rate is important as a safety factor and for controlling indoor humidity levels in all types of houses.

The furnaces installed in older mobile homes usually had a combustion air intake directly from the exterior to the combustion chamber. The furnace flue had an outer enclosure to provide a cavity used to duct outside air down into the furnace for the purpose of combustion. As a result of the connected combustion air supply and chimney, a negative air pressure inside the house did not exist. Along with the combustion air supplied by a vent specifically for this purpose, some household air was vented out of the conventional open furnaces, and domestic water heater. The typical mobile home did not have the advantage of automatically bringing in some fresh air due to furnace operations. The result in these older units is a fairly air-tight house with high concentrations of household odours and moisture. As indicated earlier however, the new mobile home standard recognizes this problem and has required the introduction of 0.5 air changes per hour into the home.

PART II FINDINGS

Based on the literature review, survey and field investigations, we find that condensation results from two sets of causes; those which contribute to the presence of moisture referred to as lifestyles sources, and those which facilitate the formation of the condensation, called building or design factors.

The lifestyle sources of humidity include the following:

- in-home humidifier, both furnace mounted and free-standing;
- food preparation, including washing and cooking;
- clothes washing and drying;
- cleaning - floors, windows, dishes, etc;
- personal hygienics; and in some more northerly areas
- melting snow or storing water for domestic use and the drying of firewood.

The contributing building and design factors included:

- lack of a vestibule to exclude snow or rain;
- ponding of water under the unit;
- lack of a vapour/moisture barrier ground cover;
- improperly operating or missing kitchen, bathroom or clothes dryer exhausts;
- poor attic and crawl space ventilation;
- snow and moisture infiltration;
- plugged unit vents;
- poor air sealing of unit walls; and
- poor or even non-existing general ventilation of the residential units.

These moisture sources and contributing building factors are explored in the following section. The information is presented as a theoretical discussion of condensation in building science terms. The findings related to mobile homes are explained as they apply to the various phenomena of condensation.

5.0 SOURCES OF MOISTURE

5.1 Effects of Relative Humidity

An airtight house minimizes loss of interior moisture (humidity) which is an energy saving feature, but may also have some health benefits. Symptoms of dry air in a house are (24):

- drying skin and nasal passages,
- respiratory infection,
- static electricity, and
- shrinkage and cracking of furnishings or buildings materials.

At a relative humidity below 30%, mucous membranes tend to dry out (25). On the positive side, dry air can have the following advantages:

- minimizes musty and other odours,
- minimizes formation and growth of mold and fungi,
- increases comfort at lower temperatures (26),
- aids in drying clothes, spills, paints, etc., and
- suppresses allergic effects of pollen (27).

Bacteria and viruses appear to be able to survive in both humid and very dry atmospheres, so humidity control will not suppress their activities (28). Growth of bacteria will however increase with higher humidity.

Too little moisture in the air can sometimes affect human comfort and can be detrimental to furnishings and building materials. Fortunately normal daily household activities can generate sufficient moisture to prevent the indoor air from becoming excessively dry. This assumes the building does not have a high air change rate to dissipate the moisture as it is being generated.

Unless protected by special packaging or coating, building materials have a moisture content level directly related to the amount of water vapour in the air. Most building materials have an affinity for moisture, absorbing and releasing it depending on the environment. For example, there is a direct relationship between moisture content in wood and the relative humidity level in the immediate environment which can be plotted on curves called sorption isotherms.

Many natural organic products have a very high sorption (ability to absorb moisture, becoming wetted, and dry out) characteristic with an orderly hysteresis effect (lagging) amounting to about 14% between drying and wetting (29). Brick, having undergone fusing by burning, has relatively few small pores and so absorbs moderate amounts of water at low and intermediate relative humidities. Concrete, a man-made mixture of stone aggregate and cement paste, has a sorption characteristic between wood and brick.

5.2 Building Process

The total weight of framing lumber used in constructing the partition walls and all floor joists of a typical two-storey site built house is about 2100 kg. If the lumber has a 19% moisture content during construction and it eventually dries to 9% moisture content, it would release over 200 litres of moisture (30). Much of the moisture will be released to the exterior since framing lumber is typically cladded on the interior with painted drywall. The concern is not with the amount of moisture released into the house, but the amount of moisture that the structure can absorb from exfiltration before condensation will result.

The indoor relative humidity of a new house is generally quite high due to the release of moisture from various building materials. Many building materials have been exposed to the elements, possibly rain, standing on wet soil, and some requiring wetting to chemically bond together such as concrete and plaster. Consequently, there is considerable moisture to be dissipated after construction. In addition, a new house must be thoroughly cleaned with detergent prior to occupancy thus adding more moisture to the materials and to the air.

The typical house requires a full year before the relative humidity in the house has reached a state of equilibrium (31). The process is slow as the released moisture from building materials increases the humidity in the house thus slowing the drying process. During this period, the building slowly settles into the soil, and later as the building materials dry, it shrinks, sometimes to such a degree as to create cracks in interior furnishings, break glass and jam doors and windows.

If there are to be any problems caused by high humidity, such as condensation, it is likely to be evident during the first year. In the second year, when the building humidity level reaches a state of equilibrium and the first year's condensation evaporates, there is generally no harm to the building structure. However the damage from condensation, such as stains on the interior finishes, may have been done in the first year.

5.3 Intentional and Unintentional Raising of Indoor Humidity

Moisture can be added to the indoor environment intentionally or unintentionally. The most obvious intentional source of moisture is the furnace humidifier in site-built houses. In mobile homes, the installation of furnace humidifiers can sometimes void the building's warranties (32). The manufactured housing industry has found that many occupants abuse furnace humidifiers by turning the setting much too high. This action results in numerous service calls with the majority of the complaints related to impaired vision through the windows and structural damage to the unit from excess condensation.

Furnace humidifiers are no longer installed in mobile homes. Our survey did not find any mobile home with a furnace humidifier. The use of portable room humidifiers are of course difficult to regulate. Our survey of mobile home owners for this study indicates that many occupants have added room humidifiers on the advice of their doctors, or believing it was necessary to relieve discomforts due to colds, or for the comfort of small children. The medical reason for having indoor humidity higher than 30% has yet to be proven yet some doctors apparently tell people to keep humidity levels up. Higher humidity levels have been perceived to be more comfortable because it reduces drying in the nasal passages. The executive of the Mobile Home Owners of Alberta believe the use of room humidifiers is one of the chief causes of condensation damaged homes (33).

The unintentional source of moisture is more difficult to control. Normal human activities can generate 7 to 14 litres of water per day from perspiration, cooking and bathing for a family of four. This added water increases to 23 litres on wash days, during washing floors, or when drying clothes without an outside vent (which contravenes the building code).

Field visits to a number of mobile homes revealed some homes have ineffective clothes drier exhaust vents. This was evident by the amount of lint scattered throughout the house. Upon further inspection, the discharge grille on the exterior was often found to be blocked by a snow drift or other debris piled against the grille. In some crawl spaces examined, clothes drier exhaust ducts had sagged and/or separated. During cold periods, moisture laden air from the clothes drier condenses and freezes along the uninsulated exhaust duct in the crawl space. The weight of the accumulated water and frost cause the duct to break the supporting straps and tear the tape connecting sections of the ducts (See Figure 5 on page 33A). Stronger attachment can be achieved with screws but this is not permitted in the ducts where lint accumulation may occur around the protruding screws. Unchecked, the discharge from the drier fills the

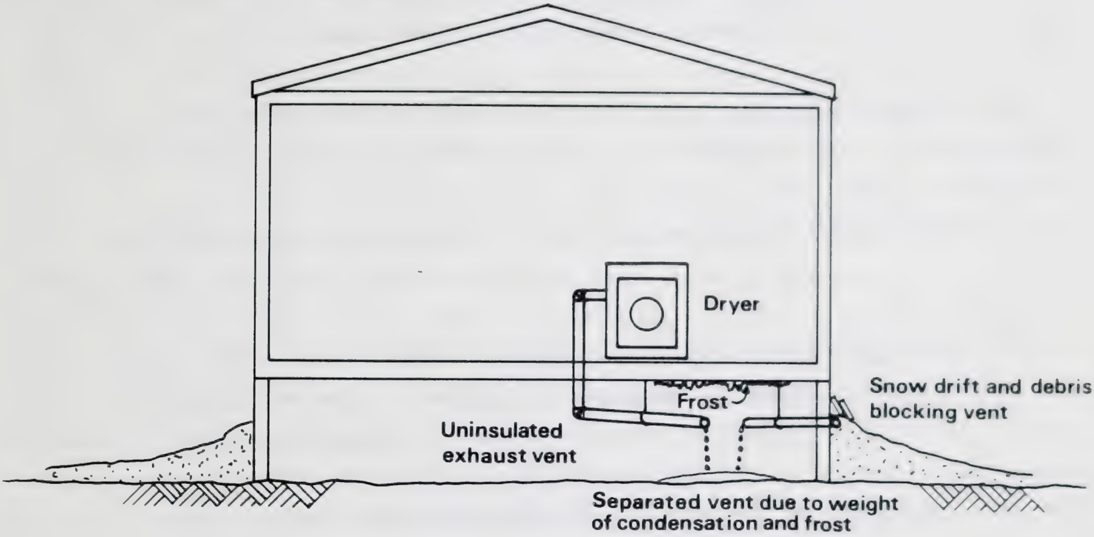

Dryer
Frost
Snow drift and debris blocking vent
Uninsulated exhaust vent
Separated vent due to weight of condensation and frost

FIG. 5: Clothes drier exhaust ducting

TABLE 1: Moisture produced by various household activities for a family of four

Activity	Moisture produced in litres. per day or activity	per week
Adult human occupants	4.31-5.45	30 - 40
Showers (8/week)	0.23 - 0.45	18 - 29
Baths (8/week)	0.05 - 0.10	3
Drying clothes (unvented)		12 - 21
Drying clothes (vented)		2 - 4
Cooking (unvented, 3 meals/day)	0.90 - 0.92	9
Cooking with natural gas (unvented)	1.22 - 2.20	9
Dishwashing	0.45 - 0.80	3
Frost-free refrigerator		9
Average size house plant	0.01 - 0.06	0.5
Floor mopping (7.4 m^2)	1.09 - 1.90	
Kerosene heater (per 4.5 L burned)	5.00	
Firewood drying in house	1.00 - 5.00	
Gas refrigerator	1.3	
Natural gas or propane space heater	1.0 L/kg fuel	

crawl space with frost, creating a potential for moisture to migrate back to the interior. It is recommended the clothes dryer exhaust ducts in crawl spaces be securely fastened and supported and well insulated to prevent condensation and frost in the ducts.

Since some household activities such as bathing and cooking are intermittent, the relative humidity level in the house also varies throughout the day. The average amount of moisture generated in a house for some common activities are listed in Table 1 on the previous page.

The amount of water vapour in the house depends first on the rate at which water vapour is generated in the home and secondly on the rate at which it is carried out of the home. It may seem fairly logical and simple to calculate the relative humidity levels in a home, but unfortunately the rate of moisture production varies. For example, perspiration rate depends on the size, age, activity and even the types of clothes worn. The amount of clothes washed, the quantity of water used for washing, the type of cooking, the length of a shower, etc. all affect the rate of water vapour added to the air. Furthermore, the air leakage rate of a house cannot be predicted nor tested with any degree of accuracy. Any test to determine the air leakage rate is affected by environmental variables such as temperature, wind, etc. A study in Newfoundland made a crude estimate of the amount of moisture generated daily in a typical house. A family of four and six, at home for an average 20 hours would generate approximately 10 litres and 15 litres respectively (34). Typical moisture generated during wash days can reach 35 litres per day.

Other unintentional moisture sources can affect the relative humidity levels in a mobile home. The predominant use of vented crawl spaces and the use of a moisture resistant membranes under mobile homes would normally eliminate ground moisture from entering the homes. Nevertheless a recent study (35) of mobile homes in

Alberta indicate some 20% have insulated skirting, thus trapping the rising moisture from the ground. Unless there is a good moisture barrier covering the earth under the crawl space, the ground moisture can seep into the mobile home and increase indoor humidity levels. This is one of the main reasons why insulated skirting in mobile homes is not recommended by the Alberta Building Standards Branch, or the Housing Division of Alberta Municipal Affairs.

While the membrane undercover under a mobile home is supposed to be moisture resistant (never vapour resistant since it can trap moisture in the floor) our inspections indicate all have openings for the entry of moisture. These openings are caused by intentional cuts to install pipes and other services, or because the undercover has been poorly cut and stapled to the underside of the house. Any negative pressure in the house can draw moisture into the house, particularly since the heating ducts are within the insulated floor space.

Unless the grade around the mobile home has a positive slope away from the unit, rainwater can collect under the crawl space. Any accumulation of such water in this area can increase the moisture content in the crawl space, which can then be drawn into the house. With an adequately vented crawl space however, the amount of moisture drawn from the crawl space is minimal. The use of a groundcover to suppress the evaporation of water from the ground is already required by the Alberta Building Code for crawl spaces. We have found in some rare instances where the building was built on low lying and wet ground, the groundcover trapped enough moisture to destabilize the foundation. In general however, the ground cover is effective and has other benefits such as suppressing plant growth.

5.4 Lifestyles

The mobile homes owned by Alberta Municipal Affairs in the Rural Emergency Home Program (R.E.H.P.) in Northern Alberta are occupied by people who are without a house primarily due to economic reasons or the lack of suitable accommodation in their community. The residents are low income families and have the use of these homes for a minimal rent. For some residents, particularly those in remote locations, the R.E.H.P. units represents the first home they have lived in which it has central heating. It may also be the first home they have lived in which comes close to being air-tight.

"Industrial" units provided by the R.E.H.P. are designed for no running water and are provided with wood stoves for heating. "Conventional" units are supplied with wood stove to supplement a propane or natural gas furnace. In isolated communities, most residents, unfamiliar with the operation of a furnace, rely upon the familiar wood stove to supplement the furnace due to the high cost of fuel. In the industrial units, of course, wood heat is the only source of heat.

In the rural houses inspected during the winter, many homes were quite warm. The habit of keeping high indoor temperatures may have originated in the occupants' previous houses where they maintained indoor temperatures of 24°C and higher especially when the outdoor temperatures plummeted. Since the stove and heater are generally located in the living room at one end of the long mobile home, the heat does not easily reach the bedrooms due to a lack of air circulation (see Figure 6 on page 36A). To counteract cold bedrooms, the living room must be overheated in an attempt to warm the bedrooms. Furthermore, controlling the heat output of stoves and oil heaters is not very precise. Some fluctuation in temperatures is expected.

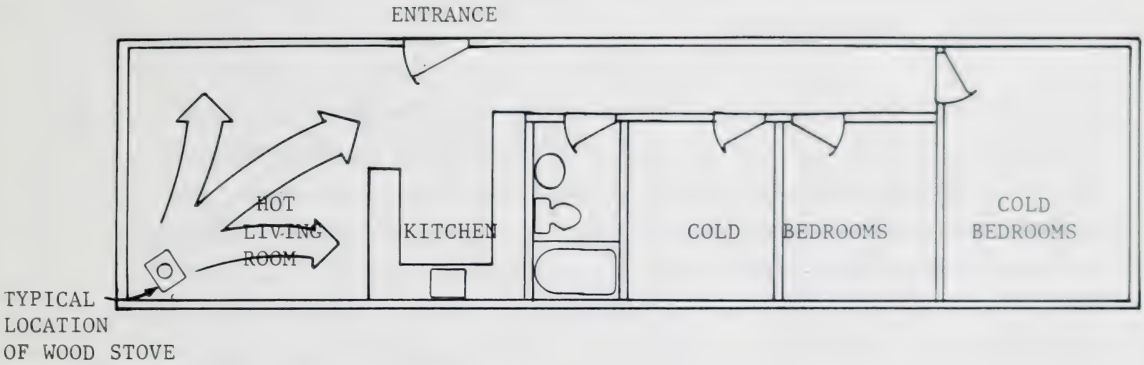
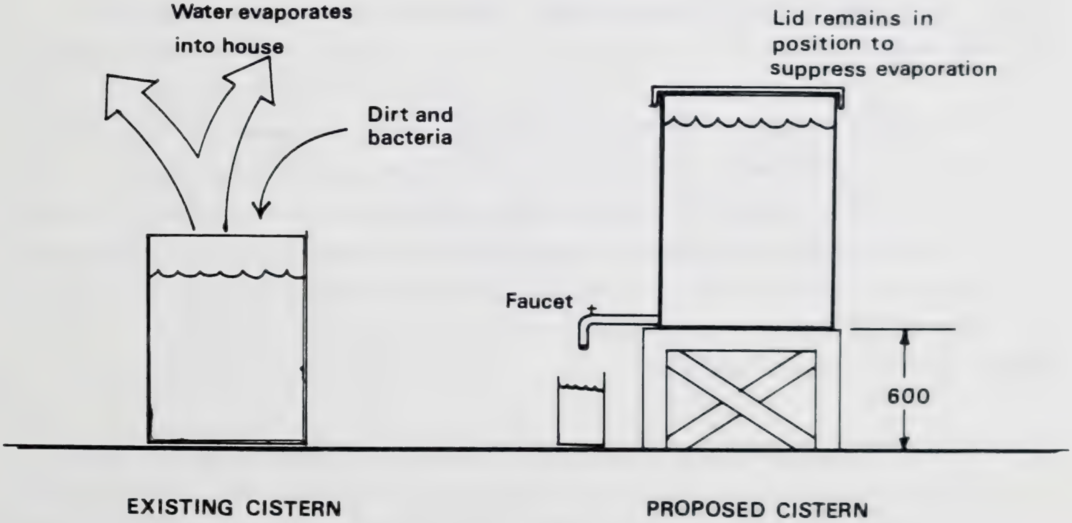


FIG. 6: Restricted space heating using wood stove


Water evaporates into house
Dirt and bacteria
Lid remains in position to suppress evaporation
Faucet
600
EXISTING CISTERN
PROPOSED CISTERN

- FIG. 7: Water cistern for homes without plumbing

Many of the occupants, particularly those in remote locations, have maintained a lifestyle which differs from the urban dwellers. Some of the major differences in lifestyles which affects the amount of condensation problems in their houses are as follows:

5.4.1 Domestic Water

In most rural locations, there are no water and sewer services available. Water or snow is brought into the house and stored in water containers, generally a 45 gallon steel drum. The water containers are not always covered which will allow evaporation of the contained water thus adding moisture to the house. A lid should be added to cover the container to reduce evaporation (and avoid contamination, dirt, etc). Water will still evaporate since the lid must be lifted in order to ladle out water. An appropriate solution is to build a strong platform approximately 600 mm high to raise the water storage container above the floor. A hose bib at the bottom of the water container will discharge only the amount of water required. The lid can be left in place to reduce evaporation (see Figure 7 on page 36A). The lid also reduces dust and dirt from contaminating the potable water.

Water for laundry, bathing and washing floors is heated initially in the domestic water heater. Our investigation revealed that some use the top of the wood burning stove for heating water. Heating and boiling such water will add much moisture to the air. One study by a housing advisor in the Alberta Municipal Affair's Rural Home Assistance Program (RHAP) determined that for a typical family of four, approximately:

- 18 litres of water was boiled for cooking and washing up per meal,
- 90 litres of water was used per load of laundry, three times per week, and,
- 45 - 70 litres was used per bath, 3 - 5 times per week.

The use of wood stoves results in more humidity added to the house. The regular transferring of wood from the outside to the inside will track in much snow, mud and water. Furthermore, firewood stored in the house will release moisture into the air upon drying. Using the wood burning stoves however, counteracts some of the moisture by creating a negative air pressure inside the house. As the chimney exhausts, it also removes some of the moisture laden air. As we have observed however, the amount of moisture discharged by the stove in this manner is insufficient to reduce the interior humidity to an acceptable level.

5.4.2 Cooking

Much of the food in these houses is cooked by boiling or using heavily water based methods which release much moisture into the indoor air. Baking or the use of pressure cookers and microwave ovens which do not generate as much moisture are not common.

The consequence of the occupant's lifestyle as described above is the generation of high humidity levels in the houses. Although many occupants may have first-hand experience and may even realize the problems of condensation such as damage to the building and growth of molds, they do not know its cause nor do they have an effective remedial measures. The lack of adequate ventilation during meal preparation in these houses is often a major contributing factor to the build-up of high indoor humidities.

5.4.3 Drying Clothes

Many of the residents in the R.E.H.P. do not have a clothes drier. Clothes are hung up to dry indoors during the winter. We observed clothes hung in bathrooms and corridors. This activity releases a considerable amount of moisture into the air. Since there are no reasonable alternatives to this situation, the residents should be advised to turn on the bathroom fan to help dissipate and remove the excess moisture. The bathroom fan will also help remove the excess moisture from the clothes thus resulting in shorter drying time.

5.4.4 Maintenance Factors Affecting Condensation

Some of the changes to mobile homes built for the Rural Home Emergency Program may be useful to the mobile home industry. Many of the older mobile home units have curved metal roofs which are being replaced. The roof develops metal fatigue from flexing in the wind and thermal movements, resulting in pinholes causing roof leaks. Another problem with the curved metal roof is its minimal attic space. Higher thermal insulation standards require thicker insulation which the curved metal roofs do not have, especially as the roof slopes towards the walls. Condensation has been common because the curved metal roofs do not have adequate cross ventilation. With the retrofitted pitched roof, the condensation problem has been reduced considerably, even without improving the air-vapour seal in the ceiling.

One of the requirements of a mobile home in the R.E.H.P. is mobility. These mobile homes are moved occasionally to supply homes for the needy. Since weight is a concern, the use of heavy building materials is avoided. Nevertheless the use of a drywall ceiling instead of the lighter composite panels has been overwhelmingly endorsed. Whereas composite ceilings readily exhibit stains from condensation, drywall often hides such evidence. The extra weight may be less important than the material's reaction to condensation.

According to the R.E.H.P. housing officers, whenever visible deterioration such as stains appear, the residents do not maintain their houses to the same degree as those without visible deterioration. Ideally the housing officers would like lightweight, more durable and stain resistant panels used throughout the house.

They suggested wood panelling or masonite backed by some stiff material such as plywood. The weight and durability of mobile homes is particularly important to their program.

5.4.5 Access to Building Supplies

Access to building materials and supplies may hinder the undertaking of repairs. Damaged or poorly installed bathroom fans for example may not be used by the occupants because of noise. Broken window glass is sometimes not repaired. Grilles for clothes dries are easily bent which reduces their effective vent opening areas. This results in a humid interior from the blocked exhaust vents. To obtain a replacement vent may require a long (3 hour) trip to the nearest building supplier.

6.0 WATER VAPOUR AND BUILDING MATERIALS

The damaging effects of high humidity can cause paint blistering or peeling, delamination of wood and other materials, and rusting or corrosion of metals. In addition, high humidity in a building may result in one or more of the following problems:

a) fungus, mold and mildew growth with resulting odours,
b) damp spots on ceilings and walls,
c) staining and dust marks on ceilings or walls,
d) water or frost on windows, and
e) decreased thermal insulation values.

These problems were observed during the site investigation but it is difficult to determine if these problems are from rain penetration and/or vapour migration. Whatever the cause, the damaging effects of water on buildings can be detrimental to the building structure. Even if the building is clad with a good rain barrier, the movement of water vapour into the building enclosure, and the resulting change in state from gas to liquid due to a drop in temperature, can provide continuous and sufficient water to affect the performance and service life of the building materials.

6.1 Molds and Fungus Growth

The conditions required for wood to rot are:

1) a food source,
2) spores,
3) suitable temperatures,
4) oxygen, and
5) moisture.

If any one of these conditions are eliminated, wood will not rot (36). While it is possible to eliminate spores with high temperatures, such a condition does not always exist within the building enclosure. Only the intermittent sol-air effects (surface heating caused by incident solar radiation) may create the high temperatures needed to kill spores. The temperature must be over 37°C or under 18°C to eliminate spore activities (37). Even when a piece of wood is sterilized, it will very quickly be covered with sufficient spores which are floating through the air, to initiate the rotting process.

Oxygen cannot be eliminated in the built environment. Unless the wood is completely immersed in water, the wood will always be fed with oxygen. Similarly the food source cannot be eliminated as it is the wood itself. Substitute materials for wood are not always practical, especially for the purpose of controlling rot due to condensation.

The only viable method left to prevent wood rot is to decrease the humidity in the air to a level which inhibits spore growth. In wood, the humidity level has a direct relationship on the moisture content level. If the moisture content of wood can be reduced to less than 20% at regular temperatures, its service life can theoretically be extended indefinately (38). This means the wood must not be subjected to a humid or wet environment during or after construction which could raise its moisture content above 20%. It is important, therefore, to prohibit the entry of rainwater. In the manufactured housing industry this problem has been solved fairly successfully. More difficult to control is the formation of condensation on or adjacent to the wood member due to air leakage from the inside.

6.2 Wet Surfaces, Damp Spots and Staining

As explained earlier, if any cold surface in the home has reached the dew point temperature, condensation will form. When a room in a house is kept cooler than other rooms, the wall surface in this colder room will also be cooler. Assuming the moisture is the same throughout the house, the exterior walls in the cooler room will be the first to form condensation. To control condensation, it is important to maintain adequate air circulation throughout the house in order to heat all surfaces evenly. Alternatively, the cooler room must be sealed to prevent moisture generated by household activities in other parts of the house from adding moisture to this room.

A thermal bridge occurs when an area of the enclosure has a higher thermal conductivity than the adjacent areas. Any solid wood in the enclosure, such as studs, plates and ceiling joists will conduct heat out of the house faster than the insulated cavity between the wood members. The areas directly behind the wood members will reach the dew point earlier than other areas and is considered a thermal bridge. Any condensation, staining, or other damage will occur first along the thermally bridged areas.

The staining of interior finishes is caused by water dissolving or leaching chemicals in the material. When the dissolved water migrates to the surface, it eventually evaporates, leaving the solid dissolved material behind. The appearance of stains on finishes not only affects the aesthetics of the building, but may indicate potential serious problems within the enclosure.

Water will cause porous materials to expand, perhaps causing warping and stressing of the material and stressing of adjacent materials. If the stresses created by the expansion is sufficiently high, materials can fail by developing cracks, bending, etc.

6.3 Dust Markings

Wetting of the ceiling and walls can result from poorly insulated enclosures, thermal bridges, or water leaks resulting from excess condensation or melted frost. As discussed earlier, when the warm moist indoor air contacts a sufficiently cold surface, be it on the outside of a cold drink bottle or on a wall, it will reach the dew point and change phase from water vapour to water. The walls may be cold from insufficient or improperly applied thermal insulation, or from thermal bridging.

Dust markings on walls and ceilings are evidence of condensation which has since evaporated. Condensation on a surface contains dissolved airborne dust and smoke. When warmer exterior temperatures or drier interior are reached, the surface condensation evaporates. The dissolved dust and smoke particles are left behind as dust marks on the wall and ceiling. Figure 8 on page 44A illustrates the process by which dust markings are formed. As the wet/dry cycle is repeated, the results become more visible, indicating the precise position of studs in the wall as seen in Figure 9 on page 44A.

6.4 Window Condensation and Frost

A small amount of condensation or frost on the glass pane of windows is normally tolerable and will not cause damage to the mobile home. The slight disadvantage of obscuring vision through the glass, and the remnants of water spots and dusting on the glass are perhaps the only concern to the occupants. If there is sufficient condensation on the windows to cause dripping, however, the potential for damages to the adjacent materials around the windows increases dramatically. Dripping water can affect the finish of the window sash and frame, particularly the sill, or it may overflow over the sill to damage the wall finish below as seen in Figure 10 on page 55.

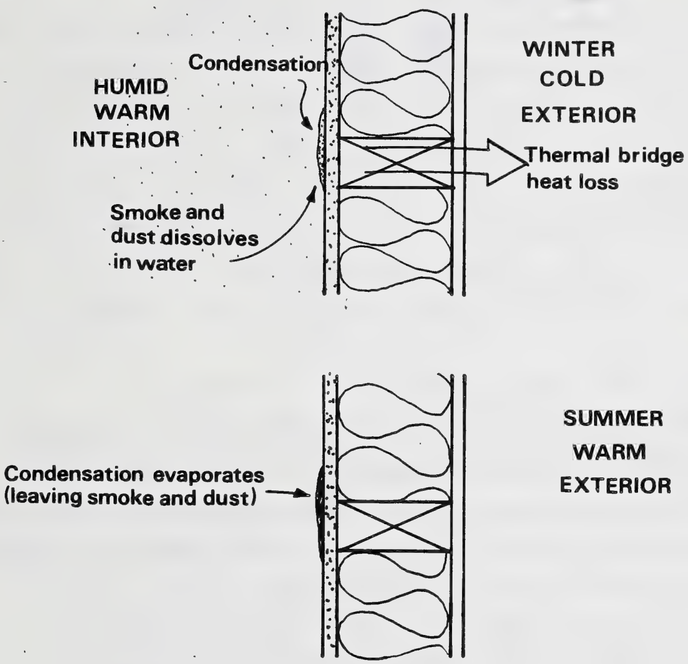


FIG. 8: Formation of dust marking

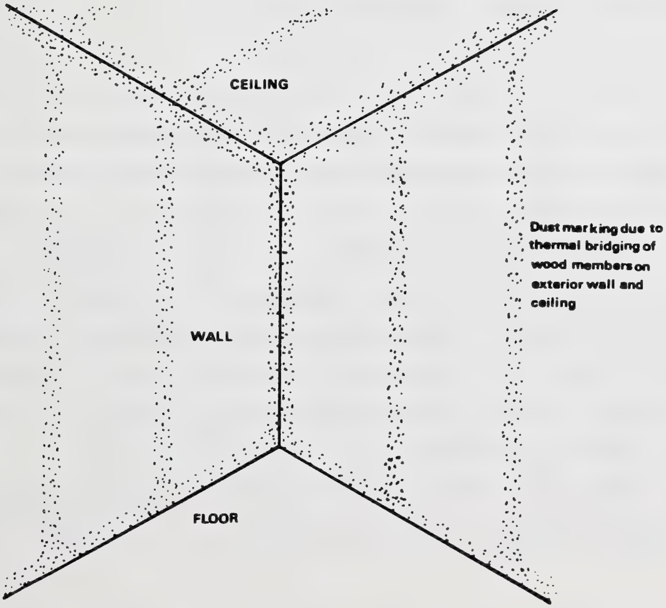


FIG. 9: Dust markings behind wood members

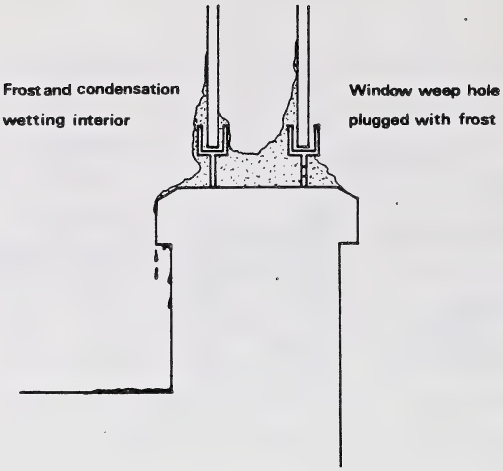

Frost and condensation wetting interior
Window weep hole plugged with frost

FIG. 10: Frost accumulation on windows

Dripping water can also penetrate paint and stain finishes to rot the wood underneath a wood window and floor. The worst damage may be water seeping between joints and cracks on the window sill to wet the insulation, rust the nails and rot the wood studs and other building materials within the wall. The damaging effects of this process may not be apparent until it is too late for preventive measures. These effects will be discussed in the next chapter, Visible Condensation.

6.5 Decreased Thermal Insulation Values

The occurrence of condensation within the insulation or any material having a lower thermal conductivity than water, will result in a major reduction in the thermal resistance value of the material. The basic technical information on the effect of water on thermal conductivity is provided by J.S. Crammerer (39). He assembled world-wide information to show that thermal conductivity of all construction materials will rise as moisture is absorbed. Moisture affects thermal conductivity because it replaces the air in the cells of foams or between fibres in fibrous materials. Even fairly thin films of water within a material will increase its thermal conductivity. When all of the air in the material is replaced with water, the thermal conductivity of the material will approach that of water.

Bomberg and Shirtliffe (40) tested the thermal conductivities of concrete and fibreboards under various equilibrium moisture contents. In one of the samples tested, the thermal conductivities measured 0.2 W/(m.K) and 0.4 W/(m.K) for moisture content of zero and 100 kg/m3. The thermal conductivities for organic materials such as wood and cellulose, can increase by about 1.25% for each percentage point increase in moisture. A number of researchers compiled the effects of moisture on the thermal conductivity of inorganic materials shown here in Table 2 below (41).

TABLE 2: Increase in Thermal Conductivity with Moisture Content for Inorganic Materials

Moisture content, %	Increase in conductivity, %	R-value
0	0	10.0
1	32	7.6
2	48	6.8
3	75	5.7
4	108	4.8
5	144	4.1

Wet insulation which has lower thermal resistance, will result in cooler interior surface temperatures. The resulting colder interior wall surfaces will form condensation and dust markings similar to the effects of thermal bridging. Furthermore, the wet insulation increases conductive heat loss through the building enclosure. It is important therefore to keep the insulation as dry as possible.

7.0 VISIBLE CONDENSATION

Similar to the process whereby moisture collects on the outer surface of a cold water glass, condensation can also occur on cold window panes or on any surface where the temperature is below the dew point. Moisture can also migrate into the enclosure to wet components inside or even pass through to the exterior where it may condense on the enclosure exterior. For the purpose of this report, visible condensation, as distinguished from concealed condensation, is that which can be readily observed by the occupants.

7.1 Windows

Visible (sometimes called surface) condensation is an indication of high moisture content in the room. Interior visible condensation occurs when moist air comes in contact with any surface which is cooled to its dew point temperature. The windows in a building usually offer the lowest surface temperature to the inside environment because they typically have the highest thermal conductivity.

The solution to dripping window condensation is to maintain a minimum temperature on the glass depending on the indoor relative humidity. Table 3 below lists the maximum relative humidity indoors to avoid window condensation on windows with at least 12.5 mm between panes, depending on the outdoor temperatures:

TABLE 3: Indoor relative humidities at which condensation will occur on windows

OUTDOOR TEMPERATURE °C	SINGLE PANE	DOUBLE PANE	TRIPLE PANE	QUADRUPLE PANE
10	55	67	76	80
0	31	47	65	72
-10	18	33	53	63
-20	9	23	45	56
-30	4	15	38	49
-40	2	10	33	44

The condensation rate varies due to fluctuating indoor and outdoor conditions, wind and air movements outside and indoor respectively, and solar radiation incident on the window pane.

Double pane windows that are not hermetically sealed were frequently observed in older mobile homes. These homes have individual horizontal slider type windows, which are inherently difficult to seal. The air between the two panes of glass is close to the average temperature between indoor and outdoor. During cold periods moisture laden indoor air migrating between the panes of glass will form condensation. If the outer pane is sufficiently vented to the outside, condensation may not form. In most units examined the amount of air leaking between the panes exceeded the exhausting capability of the standard vent holes on the outer pane. Many of the vent holes were completely plugged with dirt and frost, resulting in more condensation on the windows. Frost formation on many of the units rendered the windows inoperative. In at least four of the units examined, the floors were constantly wet from dripping condensation as a result of broken windows.

In some instances a metal window frame without a thermal break will be cooler than a thermal pane window. The first occurrence of condensation and frost will then be on the inside surface of the metal frame. Similarly, door hardware such as hinges and door knobs, and exterior hose bibs, being continuous metal from interior to exterior, will be one of the first areas to display evidence of condensation.

Condensation will collect on any surface where its temperature is below the dew point. As such there are no long lasting and effective treatments which will reduce condensation on a cold surface. The addition of a plastic sheet eg. solar reflective films, in direct contact with a window pane will only be marginally effective. The plastic film has a slightly higher thermal resistance value than bare glass, and will thus raise the surface temperature of the window. As a result, the indoor relative humidity can also be marginally raised before condensation will occur. Adding another pane of glass or plastic to the window separated by an air gap however will increase the thermal properties of the window. The warmer inner pane will result in decreased condensation.

7.2 Pipes

Indoor cold water pipes may also display evidence of condensation. These pipes are generally located in high humidity rooms such as the bathrooms and kitchens. The dew point temperature in a high humidity room will also be higher and a moderately cool pipe may show condensation. Whereas condensation on cast iron pipes can lead to rust and rust stains on adjacent surfaces, copper and plastic pipes which are used today do not deteriorate. In most instances, condensation on water pipes is not serious unless the condensation drips onto fragile surfaces or migrates into the structure. The remedy is to wrap the pipe with insulation and then with a vapour retardant material such as polyethylene to limit vapour migration through the insulation.

7.3 Cracks and Joints in the Enclosure

Visible condensation can sometimes occur on surfaces around cracks and joints in the enclosure due to incoming air, that is, infiltration. In the winter, the cold incoming air can cool the materials around the opening to below the dew point temperature, resulting in condensation or frost. Interestingly enough, the cracks and joints themselves may not show any evidence of condensation. This can occur when constant incoming outdoor air prevents the moist indoor air from reaching the opening. If the air flow ceases, however, the opening may collect moisture. This condition may be temporary, as the incoming outside air, having less moisture content, could evaporate any condensation that formed in the opening. Obviously if the condensation turns to frost and completely fills the opening, the infiltrating air will cease. Figure 11 on page 50A illustrates the formation of condensation in and around an opening in the building enclosure.

7.4 Exterior surfaces

Visible condensation may also occur on the exterior cladding. This occurs only on the side of the building with exfiltrating indoor air. As the warm moist indoor air flows through cracks and joints in the enclosure, the momentum may carry this air directly to the exterior even well after the moist air has reached its dew point temperature. Some of the saturated air will be carried off by the wind, but some will be blown against the cladding around the opening. The result is a build-up of frost around each opening where air has exfiltrated. The results are seldom damaging to the building as typical cladding materials can generally withstand water. It is likely that some of the outward-flowing air will condense within the building structure. Evidence of condensation and frost on the cladding may therefore indicate the possibility of concealed condensation.

The soffit of a house may also be saturated or have a build-up of frost. The moisture source may not necessarily be condensation leaking from the attic space. It is possible for the build-up of condensation and frost to be the result of exfiltrating air through a very leaky enclosure. As the warm moist indoor air reaches the cooler outdoor air, the natural buoyancy will float the warmer air upwards. Once the moist air is in contact with a cold soffit, condensation and frost will likely form as seen in Figure 11. The Division of Building Research of the National Research Council of Canada has documented many instances of frost forming on exterior surfaces (42). For example, a large build-up of frost on the underside of a soffit came from a clothes dryer vent located directly under the soffit.

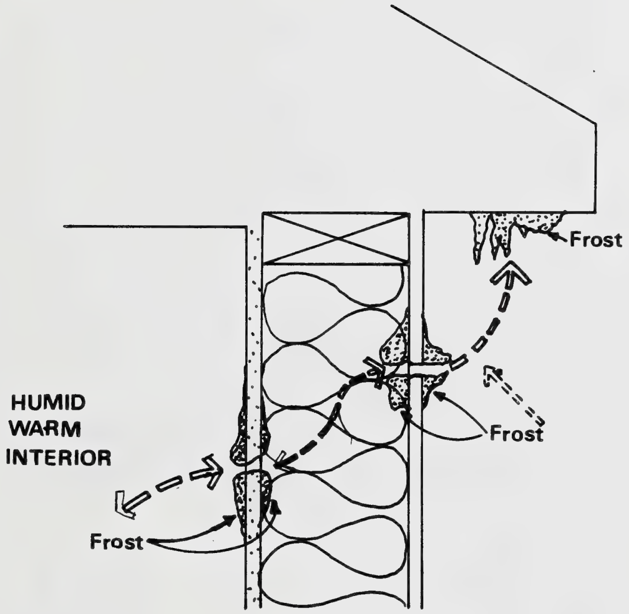


FIG. 11: Formation of frost around openings in an enclosure

8.0 CONCEALED CONDENSATION

The difference between concealed condensation and visible condensation as was discussed in the previous chapter is that there is the danger that concealed condensation may not be noticed by the occupants until it is too late to prevent serious damage to the structure. Concealed condensation can occur simply by covering a window with curtains to restrict the warming effects of indoor air moving across the glass. This results in a cooler glass surface on which increased condensation will gather. Concealed condensation may occur in a similar manner on exterior walls behind furniture that insulates the wall from indoor heat but still allows the moist air to reach the surface and form condensation (see Figure 12 below). If an insulating type material such as a pillow is leaned against the exterior wall, condensation might form on the covered wall. The interior wall is cooler due to the insulative property of the pillow. Unfortunately the pillow would not resist the transfer of vapour to the wall. As the moist air migrates through the insulation and reaches the cooler wall, it may reach its dew point temperature, thus forming condensation (see Figure 13 below). If the wall behind the pillow is below freezing, frost may actually freeze the pillow to the wall.

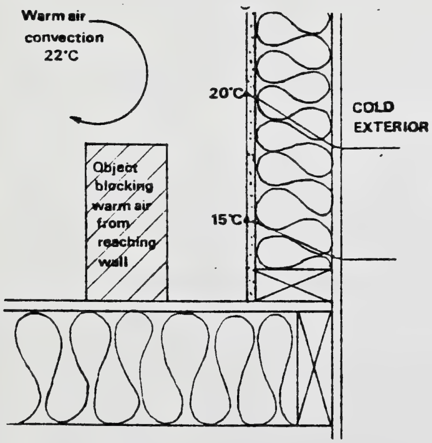


FIG. 12: Surface condensation due to lack of air flow

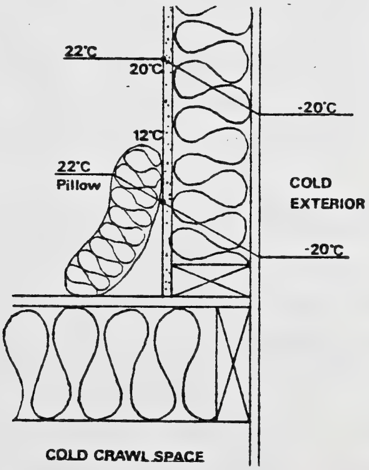


FIG. 13: Surface condensation due to additional insul. behind wall

Concealed condensation also occurs when moist air moves through cracks, gaps or holes in the enclosure. Water vapour can diffuse through the interior cladding as discussed in Chapter 3, PROPERTIES OF WATER VAPOUR IN AIR. Most building materials and finishes provide enough vapour resistance to keep vapour diffusion to a minimum. Most concealed condensation results from moist interior air leaking into the building envelope from cracks and unsealed joints as referred to in article A-9.26.5 of the Alberta Building Code 1985 (43):

> "A-9.26.5 Measures to Prevent Condensation. Investigations into moisture problems resulting from condensation of water vapour in walls and ceiling/attic spaces show that the prevention of leakage of interior heated air into these spaces is far more critical than reduction of vapor diffusion."

When water vapour enters a wall and condensation occurs, it appears as frost or liquid. If the amount of water or ice in the enclosure is small, it may change back into water vapour and be carried away by natural air movement with minor damage, if any, to the structure. If the exterior cladding is sealed or air tight, moisture that normally moves through the wall will be trapped causing a build-up of water or frost. If the temperature in the building enclosure fluctuates frequently due to the sol-air effects and variable outdoor temperatures, the frost will melt, saturating the insulation and other building materials.

The dew point position in a wall assembly can be predicted by plotting its thermal gradient and using the psychrometric chart. In normal residential construction including mobile houses, the dew point is reached somewhere in the glass fibre insulation. As water vapour migrates towards the exterior, it will eventually reach the dew point temperature. Glass fibre insulation has very little resistance to the flow of water vapour. As a result, the vapour passes beyond the dew point location without causing condensation or frosting in the insulation until it encounters the right condition for build-up (44).

Compared to the insulation, the wood studs and exterior wall sheathing have a high resistance to water vapour movement. Since the wood studs and sheathing in the winter is often well below the freezing point, the vapour turns to frost.

Since air leakage accounts for 20 to 25% of the total heat loss in a typical residence, eliminating air leakage would result in substantial savings in heating fuels consumed. While it is possible for the building enclosure to be air tight through proper detailing, quality construction, and careful sealing, it may not be practical due to the extra time, cost and the required meticulous workmanship.

Three unique areas where concealed condensation can potentially occur in mobile homes are located in the attic space, insulated floors and in the air ducts. Concealed condensation in walls is also very likely, but this topic will be discussed in Chapter 11: REMOVAL OF MOISTURE FROM WALLS.

8.1 Attic Condensation

While mobile homes do not always have an attic, most recent models have incorporated an attic as a means of controlling condensation. The ceiling of a house is sometimes a difficult place to seal properly. There are many necessary penetrations through the ceiling for pipes, wires, chimney flues, vents, and lighting. The ideal ceiling would not have any penetrations, but this is impractical and would not necessarily stop concealed condensation due to accidental or intentional penetrations. A method to avoid penetrations in the ceiling is to eliminate ceiling fixtures. The wiring for receptacles and switches in interior partitions could be routed from the floor as is the case with some mobile home manufacturers. Openings for chimneys and vents can be installed on the exterior wall rather than through the ceiling. The above suggestions may not necessarily solve the problem of concealed condensation but merely relocate potential leakage areas from the ceiling to the wall. It is still necessary to properly seal all tears and joints in the vapour barrier membrane in the walls.

As interior air migrates through openings in the ceiling, it encounters the typical glass fibre insulation. As discussed earlier, the insulation will allow the water vapour through due to its porous nature. Once the moist air reaches the attic space, some will be exhausted out through roof vents if there is sufficient air flow, but some will also encounter roofing nails, rafters and roof sheathing. Since condensation tends to gravitate towards the coldest surface, the roofing nails which penetrate the roof sheathing, will likely be the first to develop condensation. In winter, frost will likely form around the nails since the attic is generally well below the dew point. If interior air continues to migrate into the attic space, the rafters and underside of the roof sheathing will also build-up with frost.

The quantity of condensation and frost build-up on the rafters and roof sheathing can accumulate to such an extent the attic can appear to be an ice cave (45). This can lead to serious problems when the frost melts as a result of warming periods or the effects of sunlight on the roof. The water can saturate the insulation which will reduce its thermal properties. The colder temperature in the ceiling may be sufficient to cause surface condensation. Melted water from attic frost may also saturate the ceiling joists and could short-circuit wires in the roof. The water can also penetrate the polyethylene vapour barrier in the ceiling to stain the ceiling finishes or drip into the house. Attic condensation is therefore fairly serious and measures should be taken to minimize any air leakages and to provide adequate ventilation in the attic. Ventilation must be central to any condensation control program.

8.2 Insulated Floors

Concealed condensation can also occur under the floor of a building with a crawl space. Almost all mobile homes have crawl spaces and would thus be susceptible to this problem. Potential air leakage openings also exist in the floor. These include penetrations through the floor such as water and drainage pipes, wires, ducting, and vents such as the clothes dryer vent. If moist air migrates under the floor due to high interior air pressures, condensation will develop. The effects of floor condensation are less damaging than wall or ceiling condensation as any dripping water will likely move away from the enclosure due to gravity. However, it can still cause short-circuiting and saturation of building materials.

Concealed floor condensation is less frequent due to the stack effect in a house. As warm air tends to rise, it creates a positive pressure on the ceiling and negative pressure on the floor. In such a condition, air could infiltrate through the floor and exfiltrate through the ceiling. Continuously infiltrating air is less likely to develop concealed condensation, as was explained earlier.

8.3 Air Ducts

Concealed condensation can also occur in air ducts in mobile homes. If the insulation protecting the ducts is inadequate, the furnace is infrequently used because the occupants are on holidays, or the space heating is supplied by portable heaters and/or fireplaces, the ducts can become quite cold. Without the warming and drying effects of furnace heat blowing through the ducts, indoor air may migrate into the ducts. If the ducts are sufficiently cool the dew point temperature may be reached to cause formation of condensation (see Figure 14 on page 55A). The results can cause the ducts and screws to rust and the condensation may leak through to saturate the insulation and other materials.

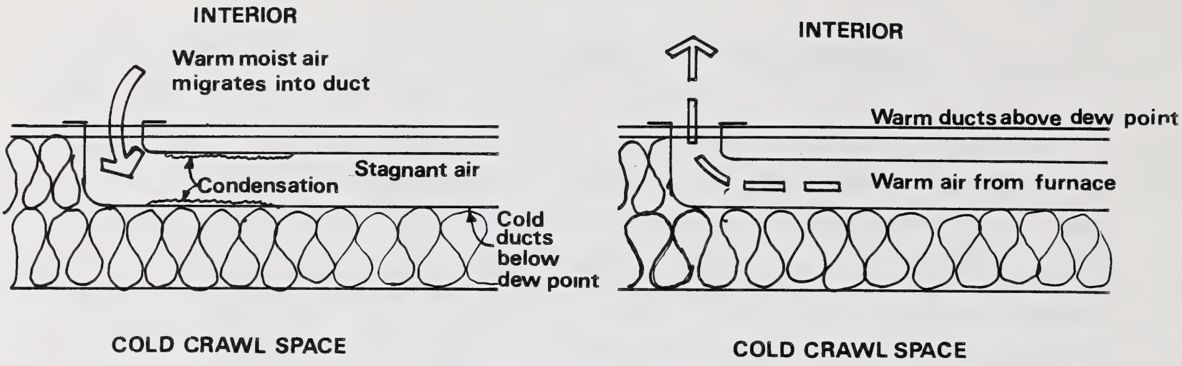
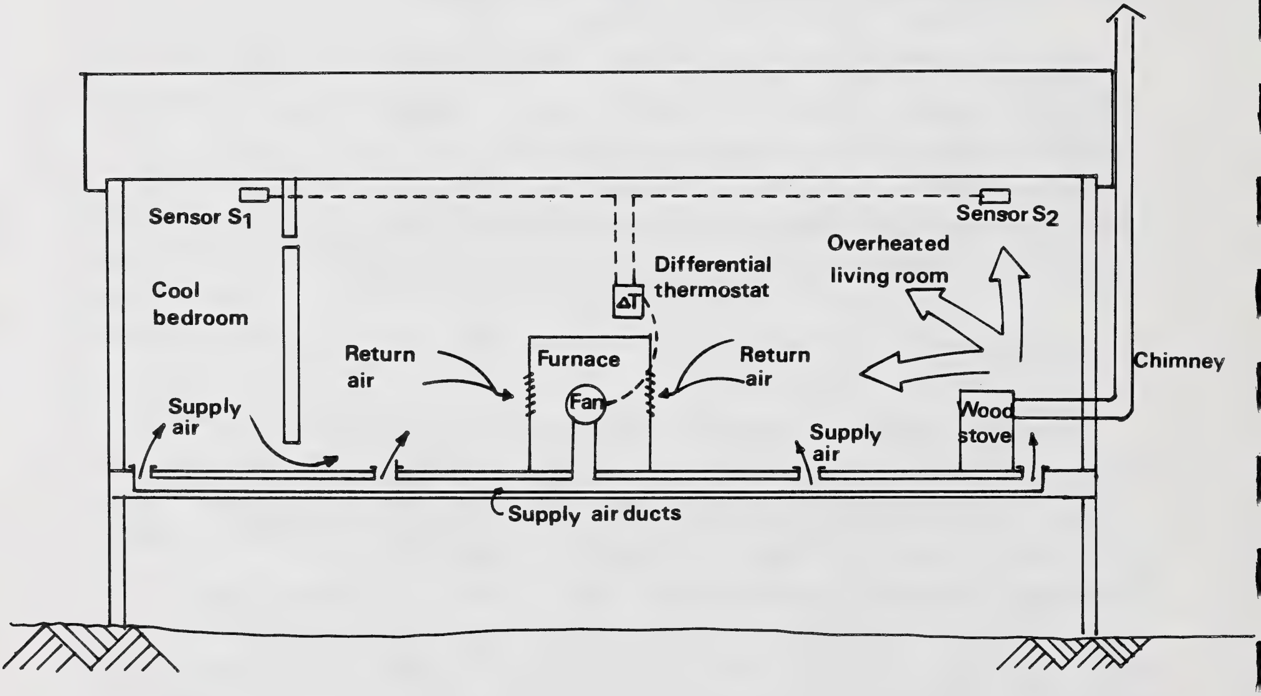


FIG. 14: Formation of condensation in floor ducts



When $S_2 > S_1$ furnace fan on

$S_2 = S_1$ furnace fan off

where $S_2 - S_1$ adjustable from 3°C to 20°C

FIG. 15: Use of a furnace fan to circulate heated air from wood stove

The obvious remedial measure to prevent the formation of condensation in air ducts during the use of wood stoves, is to turn on the furnace fan. The furnace fan will help circulated warm air in the ducts, thus raising the temperature higher than the dew point. Since tenant cooperation is not dependable, an automatic method of circulating the excess heat from one room to the rest of the house is needed. A differential thermostat purchased for approximately $100.00 can be used to turn on the furnace fan when the room with the wood stove is overheated and other rooms are cool. The differential thermostat compares the temperature between two sensors. When the temperature difference between the two sensors exceeds a certain set temperature, it sends a signal to turn on the furnace fan. The typical differential thermostat can be set between a 5°C to 20°C differential (see Figure 15 on page 55A).

One of the sensors in a differential thermostat should be positioned in the coldest room such as the bedroom at one end of the mobile home. The other sensor should be positioned typically in the living room where the space heater (such as a wood stove) is generally located. When the space heater overheats the living room, the differential thermostat will turn on the furnace fan to circulate the heat to other parts of the home. This strategy will also distribute excess heat due to solar heat, cooking, or a congregation of people gathered in the living room.

PART III REMEDIAL MEASURES AND PREVENTIVE DESIGN

9.0 RETARDING THE FLOW OF AIR AND WATER VAPOUR

As discussed in Chapter 3: PROPERTIES OF WATER VAPOUR IN AIR, the two mechanisms responsible for moisture problems within the building envelope are vapour diffusion and air leakage. These are separate means of vapour transfer and need to be controlled by two distinct means, namely the vapour barrier for diffusion and air barrier for air leakage. This chapter will discuss vapour and air barriers separately to understand their purpose, their potential effectiveness, and the types of materials to achieve the desired performances. In addition, we will discuss the success of using one material or a system of many materials to achieve the necessary air and vapour resistance in a building enclosure.

9.1 Vapour Barriers

In Canadian winters, the high water vapour level in the interior of houses has a tendency to migrate towards the exterior where the water vapour level is lower. If the house has no resistance to stop the flow of vapour through the enclosure, the migrating vapour will reach a point in the enclosure where it turns to condensation. To eliminate the process of water vapour migration, a barrier must be installed on the interior, prior to the location in the enclosure where vapour will condense. The purpose of the vapour barrier therefore is to stop water vapour diffusion through the interior cladding before it reaches a cold location in the building enclosure.

A vapour barrier is a special class of materials which offers a high resistance to the flow of water vapour. Most building materials have been tested to determine their resistance to the flow of vapour. A list of these materials and their vapour resistance or permeance (the inverse of resistance) is found in the ASHRAE Handbook of Fundamentals. The maximum allowable vapour permeance of a material intended as a vapour barrier in a building enclosure is found in the Canadian General Standards Board (46). The vapour barrier membrane for use in construction above grade requires that the permeance be not greater than 45 ng/(s.m^2.Pa), or 15 ng/(s.m^2.Pa) for the higher grade of low permeance materials such as a Type I vapour barrier when so required. The permeance rating describes the amount of moisture in nanograms passing through a square metre of material per second under a pressure of one pascal difference in vapour pressure.

Traditionally, asphalt laminated papers, metal foils, polyethylene films, oil-based enamels (and some latex emulsion) paints, among others, have been used to regulate water vapour flow. Some typical common building materials exhibiting high resistance to vapour diffusion today are

Paper and felts: - asphalt coated, laminated, roofing.
Metal foils: - copper and aluminum.
Plastics: - polyethylene.
Paints and coatings: - aluminum, asphalt based, oil-based enamels, varnishes, and varathanes.
Sheet materials: - exterior grade plywood, plastic laminates and waterproof drywall.

Since there are many types of cellular plastic insulation available in the market today, article 9.26.5.2. of the 1985 Alberta Building Code states the following:

" Lightweight cellular plastic-type insulation may be used without additional vapour barrier protection provided such insulation has a permeance rating of not more than 230 ng/Pa.s.m^2 and is installed in continuous contact with masonry or concrete walls. "

Many of the techniques for sealing cracks and small openings in the enclosure suggested later in this chapter involve the use of expanded polyurethane foam. To achieve a permeance rating of 230 ng/Pa.s.m^2 would require a thickness of 77 - 90 mm of foam. However since the purpose of foaming the openings is for air sealing and not for vapour resistance, a much smaller amount of foam is satisfactory.

The permeance rating and the resistance to moisture flow value (RMF value) of a few selected materials are listed in Table 4 below, for comparison purposes. Any material with a RMF value above 1.7 is considered to be a vapour barrier (47). Similar to adding thermal resistance values, RMF values can also be added to achieve the required vapour resistance. For example, the RMF value of a painted (oil-based primer with latex finish coat) drywall is 0.04 + 0.70 = 0.74[1]. This is inadequate to meet the vapour barrier requirements of the building code. The use of polyethylene as a vapour barrier is evident when even the thinnest 0.05 mm (2 mil) sheet already has a RMF value of 11. Special paints are now available with high vapour-retardant characteristics as seen in Table 4. To achieve a RMF of 1.7 in wood would require a thickness of (1.7/0.8) x 25.4 mm = 53.8 mm.

TABLE 4: Permeance Rating of Selected Building Materials

MATERIAL	THICKNESS mm	PERMEANCE ng/(Pa.s.m^2)	RMF value
Aluminum foil	0.03	0.0	100.0
	0.01	2.9	35.0
Polyethylene	0.15	3.45	30.0
	0.10	4.60	22.0
	0.05	9.19	11.0
Gypsum Board	12.5	2870 - 8100	0.04
Plaster	12.5	650	0.09
Wood	25.4	23 - 310	0.8
Asphalt paint on plywd.	2 coats	23	4.3
Aluminum paint	2 coats	17 - 29	3.5
Latex vapour barrier paint	1 coat		3.0
White lead/oil paint on wood	3 coats	17 - 58	2.7
Oil-based paint on wood	3 coats		1.8
Latex paint on wood	3 coats	316	0.1

[1] The application of more and/or different paints can result in RMF values that do meet code requirements.

Many older houses with no vapour barriers were able to avoid concealed condensation because they did not use plywood sheathing or other materials on the exterior which offer a high resistance to vapour flow, or, were extremely leaky due to a lack of attention to air tight construction. Water vapour migrating through the enclosure of older houses was quickly dissipated to the exterior before it had a chance to form condensation. Furthermore, the leaky houses resulted in a very dry interior which would not carry sufficient moisture into the enclosure to cause much condensation. To a certain degree, the modern house with its improved construction techniques resulted in higher interior humidity; consequently, its goal of preventing concealed condensation became more difficult to achieve and some water vapour migrates into the wall enclosure. If the rate of water migration is limited to the rate where the enclosure can adequately dissipate the moisture, the chances of concealed condensation are minimized.

Some researchers including some at the Building Research Council of the University of Illinois (48) recognize some houses have not installed the traditional polyethylene as a vapour barrier. This occurs not only in existing houses where the polyethylene was omitted but also in new construction. To alleviate some of the build-up of condensation and frost in the attic, they recommend a minimum vent area of twice the required size which is 1/150th of the ceiling area. It is hoped the greater air flow through the attic will dissipate enough moisture before too much build-up of condensation can occur. However, omitting the vapour barrier is not permitted in Canada due to our prolonged winter conditions.

9.2 The Air Barrier

With the concern for energy conserving enclosures and air tightening of the envelope, the indoor relative humidity has increased as the water vapour is no longer accidentally dissipated to the atmosphere. Small perforations or gaps occurring in the vapour barrier membrane due to sloppy installation do not present any great threat with regard to condensation when diffusion is the process in question. However, a large quantity of water vapour may migrate through the same holes carried by air. Air leakage allows much more moist air into the building cavity than does diffusion over the same period of time. The Division of Building Research at the National Research Council of Canada disputed the requirements for a vapour barrier if the building enclosure is sufficiently air-tight (49). Apparently vapour diffusion through most building materials is considered insignificant compared to the moisture carried into the wall by air leakage.

As mentioned earlier, air leakage also cause problems of heat loss and heat gain. Air leakage also results in migration of dust and dirt through the enclosure, or enables rain to penetrate into the house (50).

As discuss previously, air leakage is caused by pressure differences through:

1) Stack effect which depends upon the temperature differences between the interior and exterior and causes air to infiltrate at the bottom and exfiltrate at the top of the building.
2) Wind forces which cause infiltration on the windward side and exfiltration on the leeward side of the building.
3) Ventilation equipment which may produce small but significant pressure differences across the building envelope.

When choosing a material for an air barrier several factors must be considered: its tensile strength, its pliability, its tear resistance, its durability under bacterial action, freezing and thawing, and wetting and drying cycles.

There are several design requirements to be met in order to achieve satisfactory performance of the air barrier: (51)

1) The air barrier membrane must be continuous throughout the whole building.

2) The air barrier must be fastened to the structure so it can resist high wind loads or stack effects - inward and outward. Deflection of the barrier between the supports must be kept to a minimum to avoid tearing.

3) It must have the same life expectancy as the building, or if in doubt, must have provisions for inspection and maintenance.

4) The air barrier should be in contact with construction material on both faces to prevent its movement and possible tearing. Being located between drywall or sheathings and insulating batts or sheets is often adequate protection.

5) Where the air barrier is placed on the cold side of the insulation and there is a vapour barrier on the inside, the permeance rating of the air barrier should be 10 to 20 times higher than the vapour barrier in order to permit the free outward flow of any water vapour that gets into the insulation.

Therefore, in designing for the air barrier one must consider the sequence of construction in critical areas:

- windows, doors, and attic access hatches,
- drywall corners,
- joints between wood frame and foundation,
- chimney vents, flues, pipes and cables,
- electrical outlets and fixtures,
- milk chutes, mail slots, floor drains,
- soffit connections, and,
- joints between different exterior cladding materials.

Where the air barrier is forced to terminate at doors and windows, such components must have equal or better air barrier characteristics than the rest of the wall. In addition, the gap between the framed opening and the component must also be sealed to provide adequate air flow resistance.

The floor of a mobile home is penetrated by pipes, wiring and ducting and is therefore difficult to seal against air movement. Pipes and wiring can be sealed with caulking and spray polyurethane foam. Holes cut for ducting are seldom sealed. To seal around the floor register requires the use of a wide ducting tape as shown in Figure 16 on page 63A. Stapling through the tape and applying continuous caulking will ensure an air-tight seal.

Venting the roof, as will be discussed in the next chapter, is only one of the techniques to reduce structural damage to the attic from condensation build-up. If too much water vapour escapes from the house into the attic, the minimum venting requirement may be insufficient. For this reason, a good air vapour barrier must be utilized to minimize openings in the ceiling where moisture laden air can enter the attic. This air barrier includes the combined effects of a polyethylene layer under the insulation, caulking between all joints in the polyethylene, and plugging all holes, tears and other penetrations. The interior cladding is an integral part of the system in maintaining the integrity of the polyethylene by providing support and protection against subsequent damages. Since the polyethylene is an important part of the air and vapour retardant system in the ceiling, any necessary penetration in this material must be repaired. Some of the necessary penetrations through the ceiling are noted below along with some suggested remedies.

9.2.1 Passage for Wiring

Electrical wires must penetrate the ceiling to provide power to receptacles and light switches in interior partitions. The holes

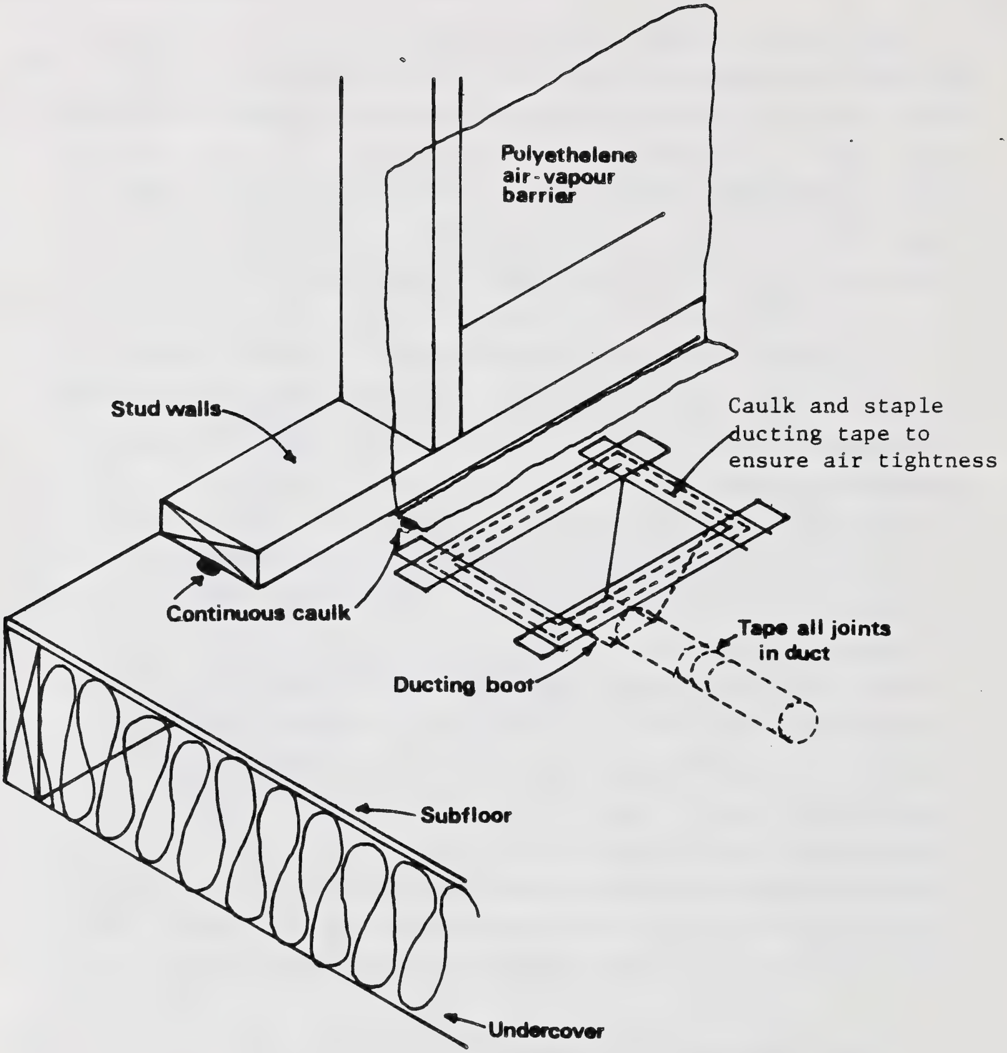

Polyethelene air-vapour barrier
Stud walls
Caulk and staple ducting tape to ensure air tightness
Continuous caulk
Tape all joints in duct
Ducting boot
Subfloor
Undercover

FIG. 16: Air sealing around floor register

drilled by the electrician are much larger than required to pass wires through. Indoor air migrates through the electrical boxes, up the partition, through the holes drilled in the top plates, and into the attic. The remedy is to fill the holes with caulking or inject expanded polyurethane insulation foam into the hole (see Figure 17 on page 64A).

Where ceiling fixtures are installed, the electrical boxes must also be air-tight. Polyethylene can be cut to wrap around the electrical boxes and sealed to the ceiling polyethylene. Alternatively, poly-pans can also be effectively used to seal this area if properly installed. As suggested earlier, minimizing the number of ceiling fixtures or avoiding having them altogether is a better solution.

Recessed ceiling light fixtures (pot-lights) are no longer recommended as the amount of heat generated in the ceiling can create a fire hazard and damage the air-vapour seals. Most authorities now recommend using surface mounted fixtures (52). Some lighting manufacturers have incorporated automatic shut-off switches which open when the temperature in the light fixture housing becomes excessive.

9.2.2 Plumbing Stacks

While no water and drainage pipes need penetrate the ceiling, a vent stack (generally a 40 mm diameter PVC pipe) must rise above the roof to equalize air pressures in the drainage pipes and prevent siphoning the water out of the traps. The vent pipes can be carefully caulked and taped to maintain the integrity of the air barrier in the ceiling. In tall buildings, the thermal expansion of the plastic vent pipe may break this seal. Installation of a pipe expansion sleeve or a flexible collar around the vent pipe at the ceiling will prevent breaking the seal.

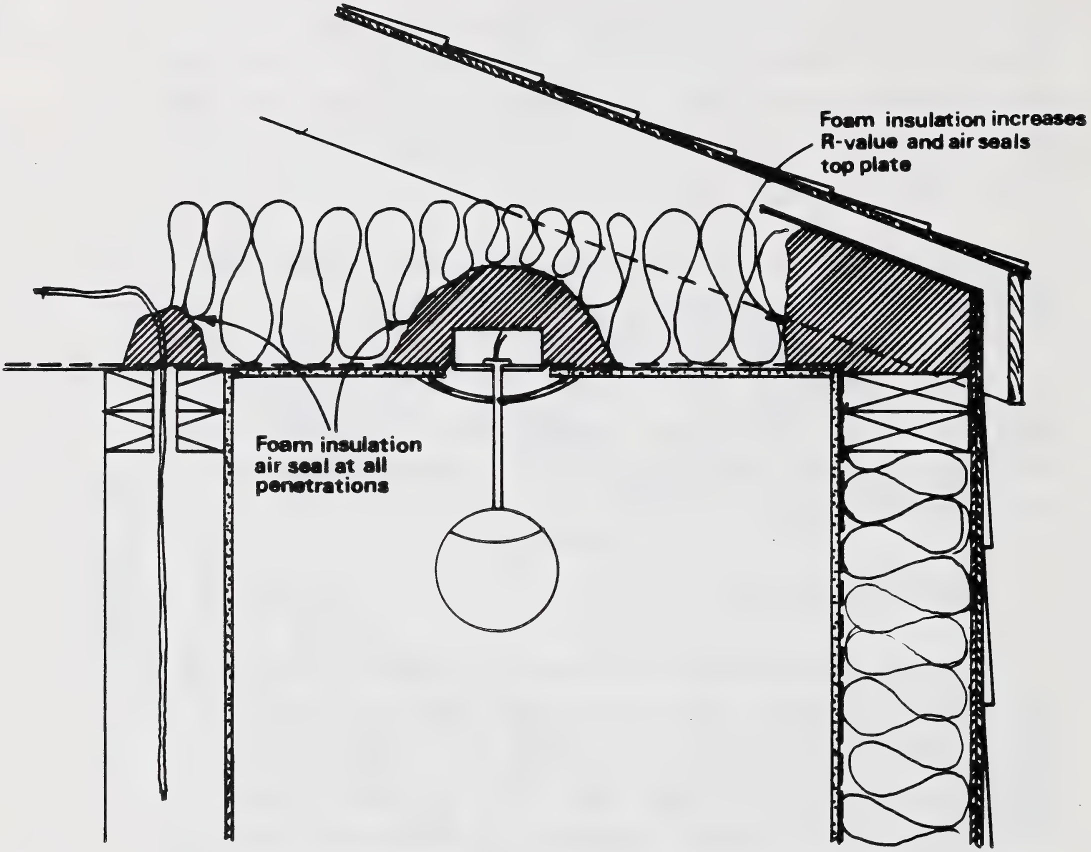

Foam insulation increases R-value and air seals top plate
Foam insulation air seal at all penetrations

FIG. 17: Air sealing of openings using foam

9.2.3 Chimney Flues

Another area of ceiling penetration is the chimney flue. This is a particularly difficult junction to seal adequately due to the high temperatures and thermal movements. The polyethylene should not be caulked to the flue as the high temperatures will not only melt the polyethylene and the caulking, but may ignite these materials. For this reason, an intermediate material must be used to provide a continuous seal. Fortunately any space between chimneys and ceiling assemblies must be fire stopped with noncombustible material (53). A sheet metal firestop is installed around the flue and connected to the ceiling joist. This fire stop provides adequate heat dissipation from the flue to avoid melting the polyethylene sheet. A heat resistant caulking such as muffler cement is used to seal the flue to the metal firestop. The practice of boxing in the flue with drywall in mobile homes helps prevent any air leakages from entering the rest of the attic space.

9.2.4 Attic Access Hatches

Although not typically used in mobile homes any attic having a space more than 600 mm at the highest point must have an access hatch at least 500 mm by 700 mm (54). While this access hatch can be on the roof or gable end, most houses have them in the ceiling. Studies indicate many attic access hatches have been improperly detailed and installed (55). Some of the problems are

- air movement under rigid insulation on top of the access hatch,
- air gaps between the ceiling insulation and the hatch insulation,
- weatherstripping omitted or improperly installed, and
- weatherstripping not sufficiently compressed to provide an air seal.

If attic access hatches are to be installed in mobile homes, proper weatherstripping and the use of tarpaulin wrapped, glass fibre insulation on top of the hatch will provide an effective air seal and thermal insulation. Figure 18 below illustrates the proper details. A more effective method is to avoid penetrating the ceiling by locating the attic access hatch at the gable end. In this position, the ceiling is continuously sealed and insulated. The inconvenience of accessing the attic from the exterior is minimal since such access is rarely needed.

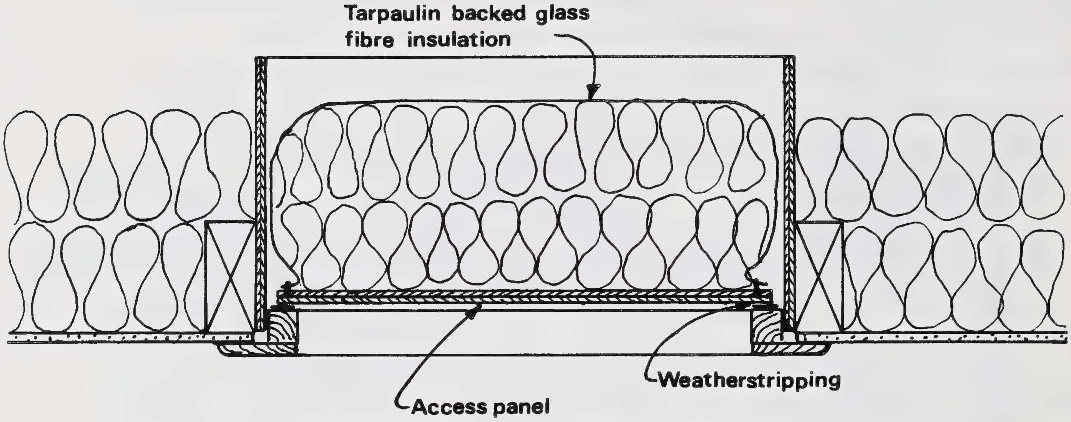


FIG. 18: Attic access hatch in ceiling

9.3 The Air-Vapour Barrier

It is obvious from the above discussion that the desired characteristics of the vapour barrier and the air barrier are somewhat similar. Many of the materials used for a vapour barrier may also satisfy the requirements for the air barrier. The air-vapour barrier is to provide not only a complete seal between the interior and exterior environment, but is a necessary first step in achieving total environmental control inside a house with minimum energy usage. It is a conservation measure which will reduce uncontrolled air changes and provide a first step in achieving environmental control.

Using the Energy Showcase Houses, built in Saskatoon, the Prairie Regional Station of the National Research Council has demonstrated that a natural infiltration rate of 0.05 air changes per hour (ach) can be achieved with proper attention to the role of the air-vapour barrier (56). As a comparison, the federal R-2000 program has set their standard at 1.5 ach at 50 Pa air pressure. To achieve this level of air tightness, designers must help builders by incorporating comprehensive details in their drawings and keeping the details at the critical area, as identified above, simple enough so that an air seal is achievable. Obviously, the more complicated the design, the more complicated is the problem of achieving an air-tight enclosure.

There has been some success in achieving air-tight construction in houses by utilizing a polyethylene air-vapour barrier membrane. The polyethylene sheet is an inexpensive and readily available material traditionally used strictly as a vapour barrier. Requiring the polyethylene to function also as an air barrier does not appear, at least initially, to be any different. The same material is used to wrap the inside in much the same manner, paying close attention to sealing joints and penetrations. To have the polyethylene vapour barrier perform as an effective air-vapour barrier however, requires significantly different techniques, greater emphasis on quality, and more consideration during the design stages. One basic difference between an air barrier and a vapour barrier is the different forces it is to resist. The vapour barrier is intended to resist water vapour diffusion while the air barrier is to resist varying air pressure forces.

It is sufficient to indicate in this report that the success of the air-vapour barrier in practice has not been entirely satisfactory. Alternative techniques have been developed to avoid the exacting workmanship of the air-vapour barrier such as the drywall approach by Lstiburek and Lischkoff (57), HUDAC's use of fully caulked plywood before the application of the drywall, and the Tyvek air barrier which wraps around the outside of the insulation.

9.4 The Air-Vapour Retardant System

It is perhaps a misconception to call anything a barrier as it implies absolute performance which in fact cannot be achieved. A total barrier to the flow of vapour through a material cannot be achieved in most petrochemical products or organic materials. Except for only a few materials such as metals and glass, some water vapour will eventually diffuse through the material. In addition it is extremely difficult if not impossible to completely stop the flow of vapour in a house by the time it is completed due to imperfections in workmanship, accidental and deliberate penetrations, and deterioration of the barrier due to environmental conditions.

A vapour retardant implies that a material has a high resistance to the flow of vapour but it does not claim to be an absolute barrier. It is not merely petty semantics to strive for an appropriate description of this function. An inappropriately named function or material can lead to inappropriate and unwarranted dependence on or trust in the material, to the detriment of the building enclosure. Understanding the limitations and difficulties in achieving a perfect barrier would indicate other measures in the design and construction must work together to minimize the migration of water vapour and air leakage. For example, polyethlene is a good vapour retardant but any penetrations must be sealed with caulking, taping, stapling, etc., which have equal or better performance than the polyethylene. To avoid deterioration when subjected to wind, sunlight and other stresses, the fragile polyethylene or such materials must be protected and supported by rigid materials. Since all of the building components in the building enclosure must work together, it is inappropriate to consider vapour resistance to be solely provided by the polyethylene membrane. The best definition of the components providing resistance to the flows of vapour and air is (at least for the time being) the air-vapour retardant system.

10.0 REMOVAL OF AIR FROM THE ATTIC SPACE

No matter how well built the ceiling in a house is, some air will leak through any tiny cracks and holes. Moist indoor air which leaks from the house to the attic can condense into water droplets on the nearest available cold surface such as the rafter and roof sheathing. Proper attic ventilation can carry some of this vapour to the outside before further moisture can accumulate and begin to condense onto the structure. This assumes the attic is adequately ventilated.

10.1 Ventilation Requirements

The 1985 Alberta Building Code recognizes the value of venting the attic as stated in article 9.19.1.1:

> "... every roof space or attic above an insulated ceiling shall be ventilated with openings to the exterior to provide unobstructed vent area of not less than 1/300 of the insulated ceiling area. Vents may be roof type, eave type, gable-end type or any combination thereof, and shall be uniformly distributed on opposite sides of the building. Vents shall be designed to prevent the entry of rain, snow and insects. The unobstructed vent area shall be determined in conformance with CAN3-A93, Natural Air Flow Ventilators for Buildings. "

Where the roof slope is less than 1:6, or the roof incorporates no attic space, the unobstructed vent area must be not less than 1/150 of the insulated ceiling area. Also, the venting should be uniformly distributed on all sides of the building (58). In all cases where venting of the roof is required, there must be a clear passage of at least 25 mm between the top of the ceiling insulation and below the top of the roof joist (59).

The required 1/300 or 1/150 vent opening is recognized by other regulatory authorities in North America. This venting requirement assumes the opening is unobstructed. In most cases, an insect screen and grille covers the opening to restrict entry of animals and debris. Such screening reduces the effective free area of the vents by at least 50%, making a larger opening or more vents necessary (60).

The intent of the roof ventilation requirements is to allow outdoor air a free passage through the attic. The location of the vents should be positioned to allow cross ventilation. This can be achieved by positioning vents on opposite sides of the roof, or placing half on the eaves, and the other half near the top of the roof. Having the roof vents separated by vertical distances will utilize the natural chimney (stack, or thermal convection) effect of warm air rising to move air out of the attic. Such roof vents have no mechanical parts to maintain, function well, and are most cost effective (61). Many of the ridge and other roof vents observed, however, were clogged with snow thereby reducing attic ventilation during the winter when it is most needed (see Figure 19 on page 73). The snow build-up is particularly common on the low sloped roofs found in many older mobile homes. Furthermore, the mobile home manufacturers have found existing roof vents let snow into the attic. As a result, perimeter ventilation around the eave of the home have been used to eliminate condensation problems without snow infiltration.

10.2 Chimney and Wind-Induced Roof Ventilators

Roof ventilators that extend above the roof were conceived to increase the chimney or stack effects to dissipate moisture from the attic. This type of roof ventilator is installed on or near the top of the roof. The warmer attic air rises to the ventilator where it is exhausted to the atmosphere by natural convection. The greatest exhaust occurs when the sun heats the ventilators, creating a greater difference in temperature between the attic and the atmosphere which increases the stack forces. With the higher ventilator designs, snow covering the orifice is minimized.

Wind induced roof ventilators also help to remove attic air. This device draws air out of the roof using the wind to turn a turbine. The turbine is designed to help draw air out of the attic when turning and can be a very effective ventilator (62). As discussed above, positioning the ventilators near the highest elevation of the roof will draw air using the stack effect, even if the wind is not blowing.

10.3 Power Ventilators

Powered ventilating fans can be activated by a humidistat. When the humidity level is excessive in the attic as a result of air leakage from the house or melting of frost build-up, the fan draws outside air through the attic for drying purposes. While this fan can be effective, it is not an ideal solution due to added electrical consumption, maintenance, and the question of reliability, particularly during the colder weather when attic ventilation is essential. The power venting of the attic may draw snow into the attic from intake openings which may not otherwise happen with natural ventilation. Furthermore, cold temperatures increase the viscosity of the lubricating oil in the fan, and the fan may be covered with frost from the moist attic air being exhausted. As a result, not many houses use power ventilators to control winter humidity levels in the attic. Where it is used, the fan may create a negative pressure in the attic, which can induce more air leakage through the ceiling (63). As mentioned in discussing flat roofs, a ventilating fan can be reversed to pressurize the attic space. This may be more satisfactory as a means of reducing infiltration into the attic from the house and also to blow air out of the attic through the eaves vent openings. The practicality of pressurizing the attic space however has not been established.

While there are inherent problems with any mechanical system as mentioned above, such uses may be warranted particularly in existing mobile houses where other measures are ineffective or impractical. The pressurization of the attic space has interesting possibilities. To determine its effectiveness would require a controlled experiment not within the scope of this study.

10.4 Flat Roofs

The National Research Council of Canada has found flat roofs to be more susceptible to condensation problems than sloped roofs (64). Factors believed contributing to the staining problems in ceilings were

1) interior partitions venting into the attic plenum through holes in the top plates,
2) party walls vented into attic plenums,
3) spaces between joists partially blocked by insulation placed over furring strips or cross-bracing, and
4) stack effect due to building heating producing air pressure difference that promotes flow of humid air through cracks and openings in the cold roof space.

Flat roofs have the unfortunate characteristic of not having sufficient height to allow for ventilation using natural convection. It is also difficult, if not sometimes impossible, to prevent the minimum 25 mm air gap between the insulation and the roof sheathing from being blocked by insulation. Insulation contractors rarely remove some of the insulation to accommodate electrical boxes and other obstructions in order to maintain the air gap above.

In a flat roof, the condensing surface is relatively close to the leakage area. This can reduce the opportunity for venting air to dissipate the moisture laden air from the house. Furthermore, if condensation does build up in the attic, the drying period is also prolonged due to the restricted air movement in this fairly narrow air gap. For flat roofs, some authorities recommend doubling the minimum venting area required to 1/150 of the ceiling area and at least 75 mm clear air gap throughout (65). Other remedies suggested by the National Research Council were to pressurize (2.5N/m^2) the roof space using a fan to prevent infiltration of air into the attic from the house (66). This remedy however is rather complicated and may not be practical. In all cases they promote the importance of a good air-vapour retardant system in the ceiling to avoid serious accumulation of condensation in the attic.

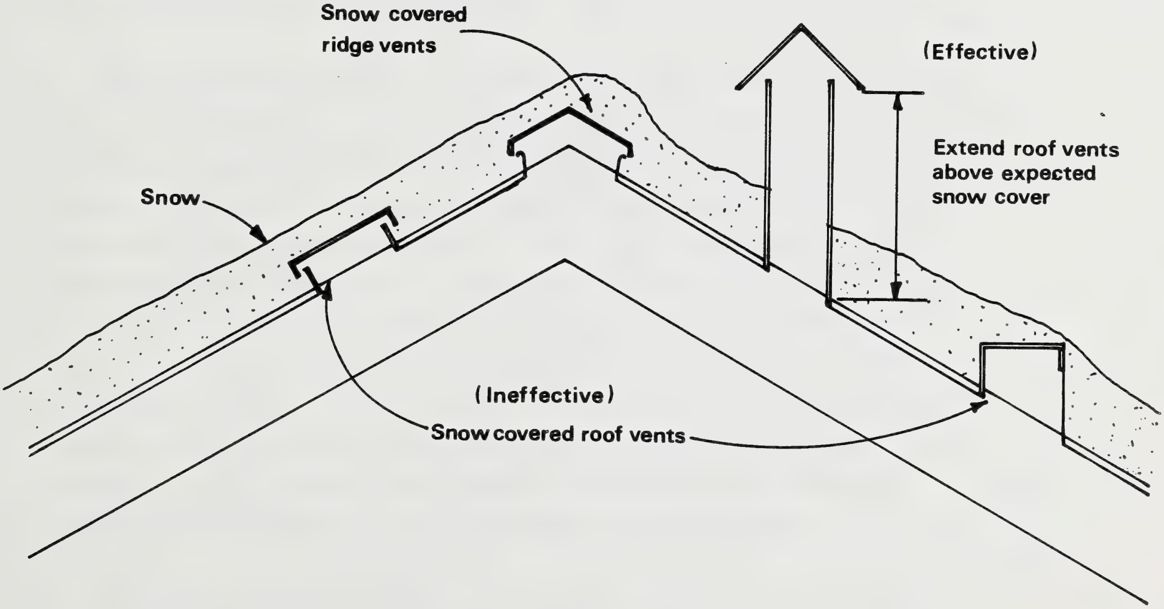


FIG. 19: Attic ventilators

11.0 REMOVAL OF MOISTURE FROM WALLS

Since it is impossible for the air-vapour retardant system in a wall to be continuous, interstitial or concealed (inside the wall) condensation must be expected. Any water vapour in the building enclosure must be allowed to escape to the outside in order to remove water vapour as soon as it migrates into the enclosure and to dry out any condensation that may have formed earlier. Furthermore, the wall must allow any excess condensation to drain harmlessly away to the exterior.

The primary functions of the exterior cladding are to resist the entry of rain and snow, to be sufficiently durable, and to be aesthetically pleasing. In cold climates, water vapour exfiltrating to the outside can build up sufficient condensation to damage the structure as well as the cladding. Evidence of such conditions include paint peeling on the exterior, wood rot, and staining.

When condensation begins to form on the structure, only a small amount of the moisture can be absorbed by the building materials. Continuous vapour migration and the formation of condensation will eventually saturate the materials and cause a number of the problems mentioned throughout this report. A wall should be designed to minimize outward migration of water vapour through the interior face of the wall. A well designed and installed air-vapour retardant system on the warm side of the insulation will considerably reduce the amount of moisture in the wall. The wall should also be designed to permit any condensation that may form in the wall to escape to the outside. A wall assembly and exterior cladding that can breathe exterior air will help to dissipate some of this moisture.

Moisture in a wall can be trapped when the wall is clad with impervious materials such as paint, metal, vinyl, etc. For reasons of low maintenance, many mobile homes are clad on the exterior with vinyls and metals. If such cladding is used, provisions must be made in the details of the wall to let moisture escape but not to permit rain penetration. Simple overlapping of wall siding and the use of battens at joints will help shed rainwater away from the wall. At one time, imitation brick sheets made of asphalt roof shingling material covered the walls of many houses. This resulted in trapping moisture in the wall thus causing considerable damage. This practice was soon discontinued.

The floor and exterior wall junctions (baseboard location) are particularly cold as evidenced by the presence of condensation and molds in the mobile homes. Concealed condensation dripping down from the attic into the exterior walls has accumulated along the bottom of the wall thus saturating the insulation and the bottom plates. The wet insulation and wood plates must be allowed to drain away to regain its thermal properties and to stop the deterioration process. Drilling weep holes through the bottom plate and floor sheathing between every stud will allow the accumulated water to escape (see Figure 20 on page 76). To prevent saturating the floor insulation, the undercover must be perforated in strategic places to permit draining the condensate.

Where concealed condensation is a serious threat, the wall cladding may be furred out similar to the rain screen wall to provide a continuous air gap behind the cladding. The continuous gap will vent the wall with fewer louvres (possibly only two) and be less conspicuous. An improvement to the louvred vents near the bottom of the wall is a continuous gap under the cladding which is also provided with an insect screen. Any water accumulated in the air gap can drain directly to the outside.

Venting the wall cavity to dissipate condensation is similar in function to venting a flat roof. The suggested 1/150 minimum unobstructed opening based on the total ceiling area is also recommended for the wall (67). The difference in elevation of the wall will create a greater stack effect than the normal roof. A 25 mm minimum air gap clearance in a furred wall should be sufficient to permit adequate air movement. It would appear that the overlapping and corrugated metal and vinyl siding used in mobile homes permits adequate venting.

The development of an air barrier which permits vapour migration may solve the problems of heat loss due to air leakage and may minimize concealed condensation. The principle of an air barrier is strictly to stop any air leakage through the building enclosure. If the air barrier is to be installed on the cold side of the insulation, it must not be a barrier to vapour (68). Using the readily available polyethylene sheets will stop air flow but will also stop vapour, resulting in trapped moisture in the wall. Tyvek, a material which has the ability to stop air flow but not vapour, is used to stop air but not vapour when wrapped around the outside of the building. At least in principle, this should alleviate many problems associated with improper application of the air-vapour membrane on the interior. In practice, the Tyvek was not always applied continuously nor were joints taped with the proper adhesive tape. For the Tyvek to function as a true air barrier, the entire enclosure must be carefully installed to maintain complete air tightness. Otherwise the areas where it is discontinuous will allow air exfiltration and condensation.

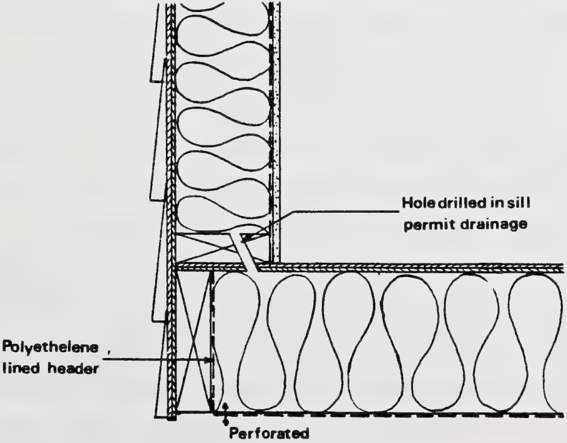


FIG. 20: Ventilation and weep holes in stud wall

12.0 REDUCTION OF INDOOR MOISTURE LEVELS

It is certain that high water vapour levels indoors increase the risk of condensation damage to the building enclosure. Even if water vapour migration into the enclosure is arrested, surface condensation on cold spots from thermal bridges or on windows can damage interior claddings, finishes and furnishings. The obvious strategy to limit the condensation to a tolerable level is to ensure the indoor relative humidity does not exceed a certain level.

Some authorities have suggested that an indication of when the maximum tolerable relative humidity has been reached is when a small amount of condensation is present on a double glazed window (69). As discussed earlier, the dew point occurring on a material is dependent on the indoor relative humidity and the surface temperature of the object. For northern Alberta, the 1% design temperature ranges from -36°C to -44°C. Such extreme temperatures rarely occur, and if they do they will last a fairly short time during the winter. The daytime temperature is generally warmer due to the warming effects of the sun. As a result, the extremely low temperatures generally occur during the early morning period, that is, after midnight. Unless there is a working portable humidifier in the mobile home, the indoor relative humidity levels during the early morning period would normally be minimal since the occupants would not be generating excess moisture through washing, bathing and cooking. For the purpose of establishing the tolerable relative humidity levels for avoiding excess condensation in a house based on outdoor temperatures, -20°C would be a typical moderately severe winter condition in northern Alberta. Table 3 (in Chapter 7, page 47) predicts the indoor relative humidity must be between 20% and 25% before condensation will occur in a double glazed window when the outdoor temperature is -20°C. In practice, higher humidities such as 30% to 35% are tolerable by the building as long as the condensation on the window panes do not drip onto the window sills. This humidity level is typical of older houses (pre 1978) in Alberta and is considered tolerable by most occupants. If a higher relative humidity level is necessary or desirable, triple glazing can tolerate 45% relative humidity before condensation will be noticed on the windows.

Since most mobile homes have double glazed windows, it is important to maintain an indoor relative humidity around 25%. While some condensation will occur on windows at this humidity and higher, it is tolerable as long as the condensation does not drip onto the window sills. In an air-tight home, most human activities will quickly dissipate enough moisture into the air to exceed this level. The solutions in this case may be one or more of the following

1) reduction of moisture leaking into the mobile home,
2) reduction of excessive moisture generating sources and activities,
3) dehumidification,
4) heat recovery ventilators, and
5) ventilation.

12.1 Reduction of Moisture Leaking Into the Mobile Home

Rain penetration can add a considerable amount of moisture into the home. Initially any water leaks of this type can be indistinguishable from the symptoms of condensation. For the purpose of this study, we will assume rain penetrations in the building enclosure have been repaired. As such there will not be any excess moisture dissipated into the indoor air due to rain.

It is possible for rising ground moisture in the crawl space to increase the water vapour level in the home above. According to Mrs. Doris Manners, secretary-treasurer of the Mobile Home Owners of Alberta, mobile homes which use the crawl space as a source for combustion air usually have chimney condensation problems. Heating the crawl space will dry out the soil below which will bring the moisture into the home. It was once hoped that the soil would eventually reach a state of equilibrium where the amount of moisture released from the soil would cease. Unfortunately the soil has an unending supply of moisture from ground water and the periodic rainfall which soaks into the soil under the crawl spaces. The rate of ground moisture given off to the crawl space can be reduced by one or more of the following:

a) berm up soil under units to provide a "bump" for for positive drainage under the units,
b) application of a continuous moisture barrier under the unit, covering all exposed soil,
c) slope soil around the skirting away from the unit to shed rainwater, and
d) direct rainwater from gutters and downspouts, if any, away from the unit.

Despite the above precautions, excess moisture can enter the crawl space from rain penetration through the skirting or the occasional plumbing leaks and spills in the units.

Crawl spaces should be fully vented and the insulation should be placed in the floor. As is the practice, a moisture barrier under the floor insulation is useful to hold up the insulation, especially during transport, and reduce some moisture migrating to the inside. The moisture barrier also serves to reduce heat loss by preventing wind from weaving through the glass fibre insulation on the floor.

It is important not to seal the moisture barrier under the floor and the insulation as it can trap moisture from spills and rain leakages. Since air tightness is never achieved with the moisture barrier, the possibility of trapping moisture in the floor is remote. A good air-vapour barrier on top of the insulation, however, is important as it will prevent moisture laden air migration into the floor insulation from the inside. Floor sheathing should be continuous using glued joints particularly at the wall and partition to floor junctions. Penetrations from wiring and plumbing should be fully caulked or filled with expanded polyurethane foam insulation. All ducting in the floor must be caulked and/or taped with a good, long lasting duct tape. These precautions will limit the amount of water vapour leaking into the floor cavity.

12.2 Reduction of Excess Moisture Generating Sources and Activities

A simple method to avoid condensation problems resulting from excess indoor humidity is to cease any activities that generate moisture. Obviously this is impractical as discussed in Chapter 5, SOURCES OF MOISTURE, where occupants by necessity will perspire moisture through the skin and expire moisture into the air by breathing. A change in lifestyle such as shorter or less frequent showers and avoiding boiling water longer than necessary can reduce the amount of moisture added to the house.

Consumer awareness can, however, be effective if the occupant perceives the detrimental effects of condensation and wishes to find a remedy. For these people, suggestions to reduce indoor humidity levels which do not drastically change their lifestyle may meet with some success. Some suggestions may include reducing the number of plants or changing them to succulent species, covering toilet bowls and aquariums, and disconnecting any portable humidifiers.

Some sources of moisture in the house can be eliminated without the direct intervention or cooperation of the occupants. For example, the clothes dryer vent should always be directly vented to the outside, never to the inside nor should it be discharged into the crawl space as was observed in some of the units examined for this study. Bathroom fans should be activated automatically when the bathroom lights are switched on. This double purpose switch is already being installed in some mobile homes.

12.3 Dehumidifiers

A dehumidifier basically condenses the water vapour out of the air. The process involves cooling the air to below the dew point by blowing it across cooling coils in the unit. A container below the cooling coils collects the condensation as it drips off the coils. A dehumidifier, therefore, is a fairly complicated and expensive machine to purchase and maintain. The cooling compressors in a dehumidifier require much electrical energy to operate; furthermore, many portable dehumidifiers require frequent servicing due to their delicate components and high internal operating pressures.

The typical residential dehumidifier removes 5 to 18 kg of water out of the air per day when the relative humidity is 60% and when operated continuously. At lower relative humidity, the dehumidifier becomes less efficient. The limitation of a dehumidifier is its ability to remove moisture from the air when a very low relative humidity is needed to avoid condensation (70). With an indoor relative humidity of 40%, there will be condensation on a double glazed window if the outdoor temperature is just below freezing. Lower outdoor temperatures typical of northern Alberta will cause condensation to drip down the window pane and damage the interior of the mobile homes. The high capital cost, maintenance, limited service life, and the inability to reduce the relative humidity to less than 40% would make the portable dehumidifier an unacceptable means to controlling condensation in mobile homes.

The Rural Home Assistance Program of Alberta Municipal Affairs, Housing division, tried a number of dehumidifiers in small houses in northern Alberta. These houses had severe condensation problems such as rotting wood, mildew and the resulting odours. They tried a number of dehumidifiers in some of these homes without success. The residents of these houses indicated there is some improvement as evident by less visible condensation on the windows. Unfortunately dehumidifiers could not remove sufficient humidity to stop the damaging effects of condensation (71). Furthermore, the dehumidifier does not address the problem of air quality.

One advantage of the mechanical dehumidifier is that there is no net energy cost for removing the moisture. Latent heat of condensing water and the electrical energy used to operate the compressor are converted into heat and transferred to the air. Large commercial dehumidifying units have recovered sufficient heat from high humidity buildings such as swimming pools, hot tubs, and ice rinks to reduce their space heating requirements. These units cost over $4,000.00, however, and would not be feasible for houses.

12.4 Heat Recovery Ventilators

One of the first domestic heat recovery ventilators (formerly called the air-to-air heat exchanger) in Canada was developed for the Taylor House located near Caledon, Ontario in 1975. The author collaborated at that time with Professor Frank Hooper, of the mechanical engineering department at the University of Toronto, and John Hix, an architect in a small company called Envirogetics Ltd. In designing an energy conserving house for Mr. and Mrs. Angus Taylor, it was recognized that the air-tight design may become too stuffy for the occupants. The purpose in developing the heat recovery ventilator was not only to bring in fresh air but to reclaim some of the heat being exhausted. The original heat recovery ventilator consisted simply of three small ducts inside a larger duct approximately 12 metres long. Metal spacers inside the duct held the smaller ducts apart and also created air turbulence for better heat transfer. When the inside air exits through the smaller ducts, the outer duct brings in fresh but cold air from the outside. As the outside air continues travelling along the duct, heat from the exhausted air is transferred through the metal separating the two air flow paths. While this experimental unit was not very efficient, it demonstrated the potential and necessity for such a unit in air-tight houses.

In 1978, the department of Mechanical Engineering at the University of Saskatchewan designed and built a heat recovery ventilator to be tested in the Saskatchewan Conservation House located in Regina. In this house, the warm, polluted and moisture laden exhausted air from the bathrooms, kitchen and clothes dryer passes along one channel while its heat is conducted to incoming fresh air in a adjacent channel. It was expected the unit would recover 70% from the exhausted air. In practice, the efficiency was closer to 50% (72). Since 1978, a number of Canadian and Japanese companies have developed and manufactured domestic scale heat recovery ventilators. The R-2000 program where a heat recovery ventilator is required in a house built to very high air tightness standards, created a market for the product.

One of the first lessons learned from the heat recovery ventilators is the obvious dehumidifying effects of bringing in dry outdoor air to replace humid indoor air. A visible exhaust of "steam" from the heat recovery ventilator indicates that much of the indoor water vapour is being discharged to the atmosphere, particularly during the winter months. A large amount of frost also accumulates in the unit, sometimes blocking the air flow out of the house, indicating considerable water vapour is being condensed out of the air. Frost blockage of the heat recovery ventilator can be avoided if the unit reverses the air flow periodically. Unfortunately, the defrost cycle brings a small amount of moisture back into the house. The reversing cycles also reduce the efficiency of the unit.

The installation of a heat recovery ventilator in mobile homes is unlikely to be justified. The percentage cost of a heat recovery ventilator in a mobile home is high compared to the cost of a site built house. In addition, the HRV's ability to reduce water vapour in the air in cold weather is limited due to frequent defrost cycles. Furthermore, the heating fuel costs for mobile homes are relatively low and saving from a heat recovery ventilator is proportionately low. The payback period for purchasing the unit to save heating fuel cost may be unreasonable. Nevertheless the technology for HRV is improving along with some price reduction making the incorporation of such devices possibly feasible in the future.

13.0 VENTILATION

The most effective means of reducing high humidity levels in mobile homes during the winter is through ventilation. As explained earlier, the outdoor air in the winter may have a very high relative humidity but its actual moisture content is fairly low. When this cold air is brought to the inside and heated, its capacity to carry more water vapour increases. As a result, the warmed outdoor air mixes with the indoor air to lower the indoor relative humidity level.

The problem with building ventilation is excess heat loss which results in high heating fuel costs. The ideal situation therefore is only to ventilate the areas of high moisture generating sources in the house such as the bathrooms and kitchen, and only when the relative humidity is higher than the dew point of interior surfaces.

Ventilation requirements for a typical family of four and six have been calculated in a recent study by CMHC (73) and are reproduced below in Table 5. The amount of moisture generated per day assumes the occupants are away for four hours daily. The amount of humidity in the outdoor air will determine the drying effectiveness through ventilation. When the outdoor relative humidity changes, the ventilation rates will also change.

TABLE 5: Typical Ventilation Requirements

Outside Air Temperature (RH = 80%)	Moisture Content Difference, kg/kg (in vs. out)	Ventilation Requirements m3/h (L/s) Family of Four 10.17 kg Moisture	Family of Six 15.26 kg Moisture
-15°C	0.0038	95 (26)	142 (39)
-10°C	0.0036	100 (28)	150 (42)
- 5°C	0.0028	129 (36)	193 (54)
0°C	0.0018	200 (56)	300 (83)

Controlling the indoor relative humidity levels with ventilation requires detecting the fluctuating humidity levels throughout the day. A manual method involves the occupant's understanding and co-operation. This method may be as simple as turning on an exhaust fan when condensation appears on the window, and turning it off when the condensation disappears to reduce heat loss. Unfortunately such co-operation is not always dependable.

A semi-automatic method of controlling indoor relative humidity levels with ventilation may involve the occupant's unconscious participation. An exhaust fan in the bathroom may be turned on at the same time as the bathroom lights. This method assumes the occupant will be generating moisture whenever the bathroom is used. A timer can be connected to the exhaust fan to continue exhausting moist air after the lights have been turned off. There will be instances when no moisture is generated such as combing one's hair or applying make-up. The exhaust fan in this case may simply be ejecting warm indoor air from the house thus wasting heating fuel. In addition, the single switch for the bathroom lights and exhaust fan is not always practical in bathrooms with windows. For example, if a bathroom has a window, there may be sufficient daylighting in the room to make the electric lights redundant. As a result, the bathroom lights and exhaust fan will not be turned on and the excess moisture generated in the bathroom will not be exhausted. The semi-automatic exhaust fan would not necessarily be effective in kitchens for the same reason as the bathrooms. It does not appear that there is an ideal semi-automatic method of reducing high indoor relative humidity levels through ventilation.

The fully automatic ventilation system may be the only consistent and effective method of limiting indoor relative humidity levels. Since August of 1984, new mobile homes have incorporated a method of supplying fresh air directly to the furnace. When the furnace is turned on, the furnace fan draws outside air into the house. This results in fresh hot dry air being circulated by the furnace throughout the house. The moist indoor air is then pushed out through the exhaust vents in the bathrooms, kitchen, and clothes dryer. If the house has monitor vents, as are commonly found in mobile homes, the exhausted humid air can also migrate out through this opening. The advantage of having fresh air brought directly to the furnace is the ease and economy of distributing this air throughout the house using the regular ducting system. At least in theory, the furnace will bring in more fresh air during the winter when the need to reduce indoor humidities is also important. As the furnace responds to the outdoor temperature, the entire system has a synergetic relationship. It has not been determined if the required 0.5 air change per hour as stipulated and incorporated in mobile homes since August 1984, is being achieved in these units. We did not find any condensation problems in any of the new mobile homes having this air change feature.

A concern arises with the introduction of fresh air using the furnace fan regarding the potential for exfiltration due to increased air pressure inside the house. There will always be a slight positive air pressure inside when outdoor air is mechanically brought into the building despite the existence of the normal vent openings. Exfiltrating air may cause interstitial condensation in the building enclosure. Our field investigation has not observed any interstitial condensation as a direct result of the higher pressures caused by the furnace fresh air intake. The monitor vents and ducting for the exhaust fans in the bathroom and kitchen may have provided sufficient air equalization orifices.

The anticipated air distribution and recommended location of monitor vents for a typical mobile home with a furnace supplying 0.5 air change per hour is illustrated in Figure 21 on page 87A. Placing exhaust air vents in highly humid areas such as the bathroom, kitchen, and entry will help to remove excess moisture from the house. In addition, odours generated in the three areas will also be exhausted directly without having to turn on the exhaust fans.

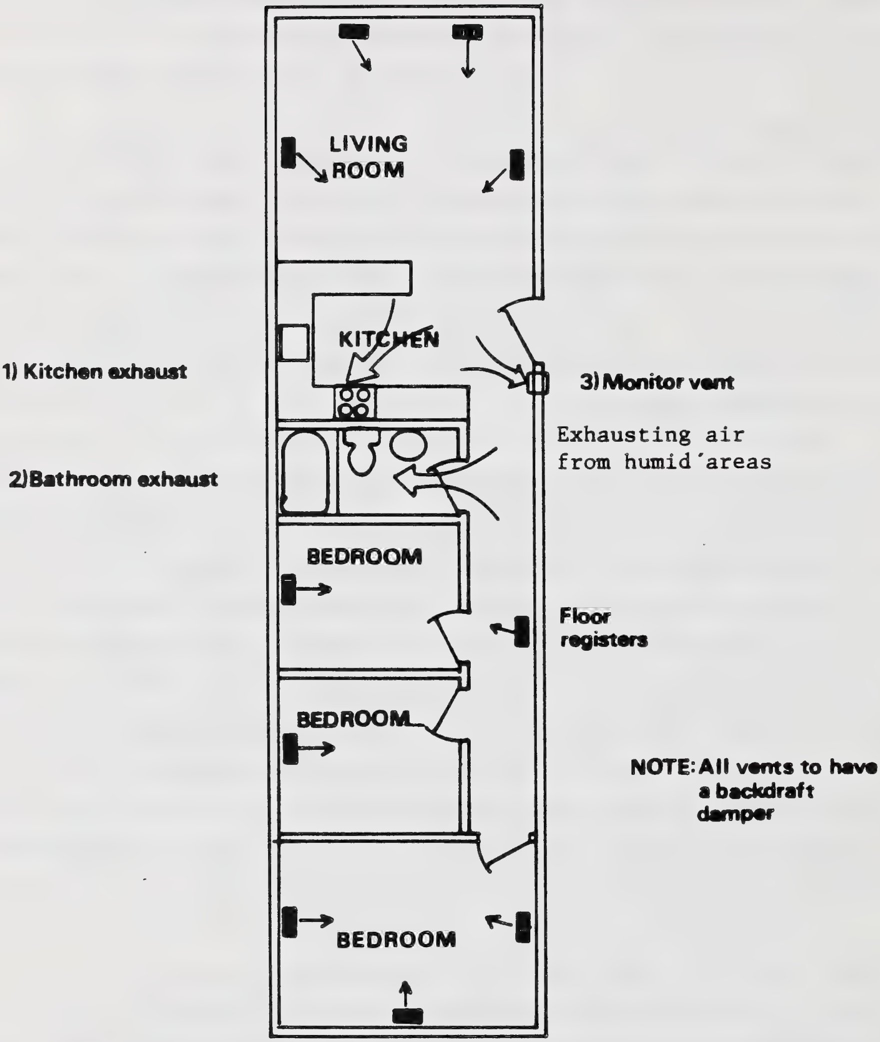


FIG. 21: Air circulation and exhaust with furnace supplied fresh air

Nevertheless, the amount of moisture generated by some activities in these areas such as bathing and cooking, will exceed the amount of air being exhausted. During these activities, the exhaust fans in the bathroom and kitchen should be used.

A minor problem with the indiscriminate ventilation of indoor air from all rooms of the house as achieved by the 0.5 ach furnaces, is the excess heat loss. Air from rooms which do not have many moisture generating activities, such as the bedrooms, is exhausted at the same rate as high humidity room such as the bathroom. It is only logical to exhaust those rooms with higher moisture producing activities. Fortunately, the openings provided by the exhaust vents in the bathrooms, kitchen, and clothes drier will help remove some of the air from these areas before air is removed from other areas.

The bathroom and kitchen exhaust fans are used by mobile home residents almost solely for the control of odours. Our questionnaire and discussions with the residents indicate that most do not realize the use of these exhaust fans can also control high, indoor relative humidity. When we suggested this possibility, there was some reluctance to use these fans because of the noise produced. One method of reducing fan noise is to use resilient mounts but none of the mobile homes examined had such features. Another method to reduce fan noise is to lower the fan speed with a dimmer. Even though this is a fairly inexpensive feature (approximately $8.00), none were found during the course of our investigation. Some limit on the dimmer may have to be established in case the exhaust fan becomes inefficient if its speed is too slow. As a general rule, the fan should not be decreased by more than half of its design speed, or when it takes longer than 10 minutes to exhaust the moist air in the typical bathroom.

The best noise suppressing technique is to mount the fans in a remote location from the living areas such as in the attic or the crawl space as seen in Figure 22 on page 89A. Whereas any condensation forming in the insulated exhaust ducts in the crawl space would drip harmlessly onto the ground, the attic alternative may require a condensate drain line directed to the outside. This simple apparatus can be installed in existing mobile homes having a condensation problem. The cost for materials and installation is approximately $400.00. Access for maintenance would be necessary.

Another method of ventilation to control the amount of moisture inside a building is to automatically ventilate rooms having high moisture production. A humidistat activated exhaust fan located in the bathrooms and kitchen of a house may be sufficient to control the amount of indoor humidity (see Figure 22 on page 89A). When the humidistat senses a preselected indoor relative humidity level, it turns on the fan in that room. Fresh air is brought in to replace the exhausted air through special openings such as the monitor vents. It is important to locate and design these monitor vents so that they cannot be easily detected or sealed by the occupants. This method reduces excess heat loss through indiscriminate ventilation of the home and concentrates on exhausting high moisture laden air where it is generated.

As indicated in Chapter 10, REMOVAL OF AIR FROM THE ATTIC SPACE, stack effect can be used to exhaust air from an enclosed space without the use of an exhaust fan. A number of products are available which opens an air damper to permit the natural exhaust of indoor air. Connected to a humidistat, these dampers can maintain a preset indoor humidity level. Typical cost for retrofitting the automatic dampers and humidistat to an existing roof ventilating duct is approximately $100.00. This cost includes three dampers and a humidistat but would not include labour. Typically two dampers are needed on the ceiling and one located near the bottom of an exterior wall or on the floor for supplying replacement air. The long term

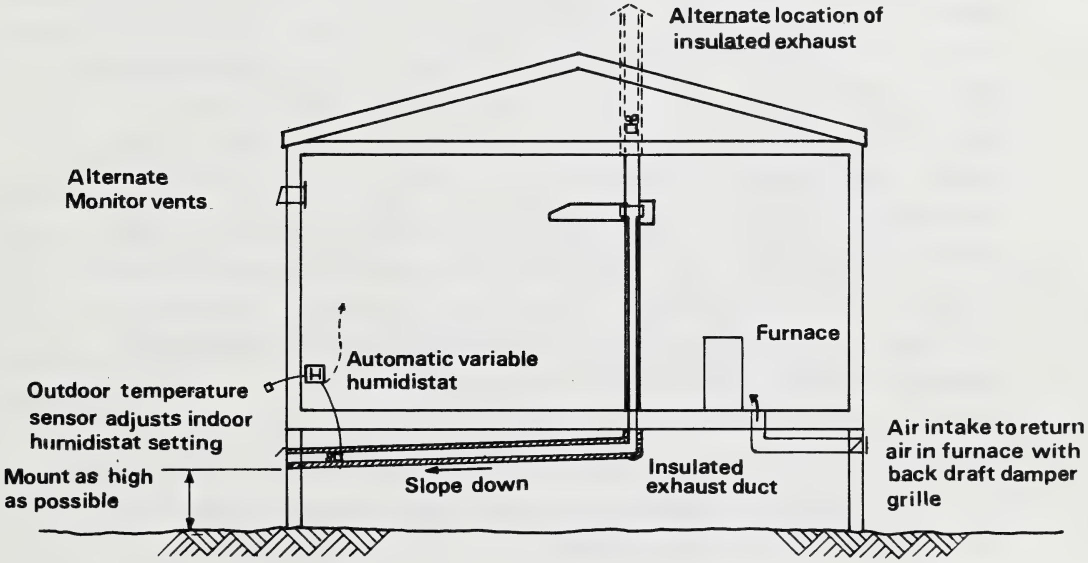

Alternate location of insulated exhaust
Alternate Monitor vents
Furnace
Automatic variable humidistat
Outdoor temperature sensor adjusts indoor humidistat setting
Mount as high as possible
Slope down
Insulated exhaust duct
Air intake to return air in furnace with back draft damper grille

FIG. 22: Variable humidistat operated exhaust fan

durability and dependability of these automatic dampers, particularly when these units are subjected to potential frost conditions, must be addressed.

Heat loss as a result of venting moist indoor air can be reduced by limiting the amount of exhausted air to a tolerable level of condensation. For example, higher indoor relative humidity will not create condensation if the outdoor temperature is not as cold. Since the objective of ventilating indoor air is to eliminate condensation problems, maintaining the indoor relative humidity at a constant 25% is only necessary during the coldest periods. To set the humidistat operating the exhaust fan at this level would needlessly increase heat loss and waste electricity by powering the fans during milder outdoor temperatures. Furthermore, the exhaust fan would operate continuously during the summer when the outdoor air, with its higher moisture content level, will no longer have the drying capability as in the winter. The solution is to install an automatic variable humidistat which adjusts according to outdoor ambient temperatures. A tenant adjustable humidistat has not been satisfactory. In one case brought to our attention, the resident of a mobile home maintained his humidistat at 72% thinking it was the thermostat setting. The tenant had wondered why the specially installed ventilating fan had no effect on the condensation problem.

In essence, this method of controlling indoor humidity levels is a combination of the standard air change requirements of mobile homes with the added benefits of automatically venting high moisture producing rooms when needed. This method minimizes condensation damage from a pressurized building, reduces heat loss from excessive ventilation, and reduces the operating cost of the exhaust fans. When selecting the appropriate size exhaust fan, care must be taken not to depressurize the home to the point where there is insufficient air for combustion appliances such as wood stoves and fireplaces. Dependability and maintenance of the exhaust fans of course need to be improved if it is to be used more frequently than usual.

PART IV CONCLUSIONS

14.0 CONCLUSIONS

All types of houses can have potential condensation problems due to moisture generated by ordinary household activities. Buildings that are built for air tightness increase the likelihood of condensation problems from trapping moist air. Whereas older leakier houses dilute the level of moisture (and contaminants) in the house, the air tight house tends to keep that moisture inside. For obvious health reasons and to avoid condensation damage to the building, it is necessary to ventilate the house.

The mobile home is more prone to high indoor humidities and indoor pollution than site built houses due to its smaller volume. Assuming the lifestyle and demography of the occupants are the same, the smaller air volume of the mobile home cannot readily absorb as much moisture as the larger site built house. As a result, the relative humidity levels inside the mobile home will rise fairly quickly.

Most site built houses have a built in mechanism to ventilate them, thus reducing the build-up of water vapour which is not available in mobile homes. Furnaces in most site-built houses have chimneys which continually draw air from the home. The pre-1984 mobile home furnace was not only provided with its own combustion air, as are today's model, but it was also isolated from the humid indoor air. Further, there was no requirement for the supply of fresh air into the unit; consequently, these older units must be vented by other means.

Our investigation found the 0.5 air change per hour standard for recently built mobile homes has solved many of the problems of high indoor humidities and the question of air quality. Our limited survey of manufacturers, dealers, regulatory authorities, and occupants of mobile homes indicated that no evidence of a serious condensation problem has been reported to date in the newer mobile homes.

Obviously a wider sampling and longer period of experience with these new units will give a more dependable answer. Our concern with this technique of controlling condensation is the potential to create interstitial condensation due to a pressurized interior. Only time will tell if this concern is valid.

An exhaust fan controlled by a variable humidistat as a means to control indoor humidity is a worthwhile option. The exhaust fan minimizes the potential for condensation in the building enclosure by slightly depressurizing the home.

There appear to be other areas in the design and assembly of mobile homes that should be addressed in order to minimize the chances of condensation damage. For existing homes, the remedial measures are as follows:

1) Clear existing monitor vents of obstructions.
2) Reconnect and/or repair damaged clothes drier ducting and vent to outside, not to crawl space.
3) Clear obstructions from blocking clothes drier grilles,
4) Clear obstructions from window weep holes.
5) Replace broken windows.
6) Repair bathroom fan (if noise is still a deterrent to its use, replace with a quieter fan and use resilient mounts or install a dimmer to slow fan speed).
7) Replace kitchen recirculating fan with venting model.
8) Add an entrance vestibule for the purpose of keeping snow and mud from entering the house.
9) Slope grade around the house.
10) Provide a groundcover moisture barrier.
11) Replace roof mounted vents with stack vents which extend at least 600 mm above the roof.

It is clear that built-in energy saving techniques and devices for a house can be rendered useless by the attitude and lifestyle of the residents. For example, a triple glazed window with thermally broken frames cannot reduce heat loss if the windows are kept open. A highly insulated building enclosure cannot lower heating fuel costs as much as predicted if the doors are constantly being left open. The same arguments can be made for condensation control. The techniques and devices suggested above can help reduce condensation damage in a mobile home. The degree of success, however, rests with the residents.

The amount of moisture generated by household activities can exceed the ability of the devices and techniques incorporated for the purpose of reducing condensation. It is for this reason we suggest a program of consumer awareness whenever there is a condensation related complaint or inquiry. This program would inform the mobile home residents of the causes and cures for condensation. There is available literature which addresses this problem.

The following measures require modest adjustments in the lifestyle of the mobile home user; consequently the resident owner or tenant must recognize or be shown the need to reduce condensation and become involved in the correction program:

1) Remove or disconnect any humidifying devices.
2) Do not hang clothes to dry indoors.
3) Do not leave bathtub and hottubs filled with water (if soaking clothes is necessary cover container with polyethylene or other material).
4) Ensure the clothes drier vent is not obstructed by snow or debris.
5) Clean the lint filter in the clothes drier regularly.
6) Clean the furnace filter regularly to ensure good air circulation.
7) Use the bathroom exhaust fans when bathing.
8) Use the kitchen hood fan (if vented) when cooking.

9) Open the windows for a short period when condensation becomes excessive.
10) Reduce the number of house plants.
11) If a water cistern is needed, use a lid and faucet.
12) Bring only a minimum amount of firewood into the house at any one time.

For new mobile homes, techniques and devices which can be employed by manufacturers or dealers to mitigate the problems of condensation are listed below and grouped in terms of manufacturing plant measures and on-site installation measures.

a) MANUFACTURING PLANT MEASURES

1) Identify and eliminate any thermal bridging in the enclosure.
2) Ensure a good air-vapour retardant system throughout.
3) Avoid the use of ceiling mounted fixtures.
4) Continue the use of a gypsum board ceiling.
5) Drill weep holes in the sill and top plates.
6) Install only venting kitchen exhaust hoods.
7) Install a quiet bathroom exhaust fan.
8) Position the clothes drier on exterior wall.
9) Have factory installed clothes drier ducts and grille equipped with backdraft dampers.
10) Insulate clothes drier ducts if in crawl space and slope towards exterior.
11) Position any venting grilles as high as possible to avoid obstruction by snow and debris.
12) Retain monitor vents located near the entry.
13) Install a differential thermostat to circulate air throughout the home using the furnace fan.
14) Use only roof ventilators that extend at least 600 mm above the roof.
15) Use a pitched roof and full attic ventilation.
16) Use hermetically sealed windows and thermal broken frames.
17) Consider the use of triple glazed windows where excess moisture is expected.

18) Incorporate an entrance vestibule for coats and boots.

b) ON SITE INSTALLATION

1) Ensure crawl spaces are adequately vented.
2) Require that dealers inform mobile home purchasers of the causes and cures for condensation.
3) Ensure grade slopes away from the house.
4) Ensure that ground cover is installed in the crawl space.
5) Ensure skirting is maintained to prevent entry of animals and continues to vent the crawl space.
6) Provide adequate roof rain gutters and downspouts to prevent rainwater from entering the house.

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APPENDIX A: INVESTIGATION PROCEDURE

1) PROBLEM IDENTIFICATION.
(Condensation in manufactured housing)

- concerns regarding shortened service life of mobile homes in northern Alberta.
- determine the extent of condensation problem in old and new mobile homes.
- investigate cause(s) of problems and suggest remedies for existing dwellings and for new construction.

2) SCOPE OF INVESTIGATION.

- define areas of investigation appropriate to this study.

3) LITERATURE.

- review reports, journals, and other documents relevant to this study.
- discuss and summarize consensus if any on the problem.

3a) BUILDING SCIENCE.
- psychometry, vapour flows and pressure, and diffusion.
- function of the building enclosure.

3b) BUILDING STANDARDS.
- building codes, standards and practices.

3c) AGENCIES.
- regulatory agencies and associations.

3d) PRIOR RESEARCH.
- consultant's reports, journal articles and books.

4) COLLABORATION.

- discussions about this study, personal experiences, actual and proposed remedial measures, and extent of condensation in new and older mobile homes.

4a) BUILDING STANDARDS.
  - building regulations, monitoring and enforcement of standards.
  - investigation and recommendations.

4b) MANUFACTURERS.
  - their perceptions, understanding and experiences with condensation problems.
  - warranties, maintenance and solutions.
  - construction practices.
  - consumer awareness and cautions.

4c) DEALERS.
  - their perceptions, understanding and experiences with condensation problems.
  - site servicing.
  - purchaser awareness.

4d) MOBILE HOME OWNER ASSOCIATIONS.
  - their perceptions, understanding and experiences with condensation problems.
  - information and referral services.

4e) MOBILE HOME RESIDENTS.
  - owners, renters and emergency/temporary occupants.
  - their perceptions, understanding and experiences with condensation problems.
  - remedial measures if any and its success.

5) QUESTIONNAIRE.

- to establish the extent and details of condensation problems in mobile homes.
- telephone and door-to-door survey of mobile home occupants, landlords and service personnel.

5a) OCCUPANT PERCEPTIONS.
  - their understanding of condensation problems and potential solutions.

5b) OCCUPANT LIFESTYLES.
  - correlating the extent of condensation problems with occupant composition, understanding and activities.

5c) PHYSICAL CONDITION OF DWELLINGS.

- age, model, location and overall quality and condition of representative mobile homes.

6) FIELD INVESTIGATION.

- examination of mobile homes from its assembly to final destination.
- performance of mobile homes subjected to varying environmental conditions and occupant activities.

6a) FACTORY.

- construction practices of various manufacturers.
- personnel understanding of condensation and their attitude and approaches to the problem.
- solutions to potential condensation problems as incorporated in current and future models.

6b) DEALERS.

- condition and set-up of mobile home units.
- personnel understanding of condensation and their attitude and approaches to the problem.
- site servicing details and policy.

6c) MOBILE HOME SITES - monitored data.

- observe, record and monitor environmental conditions.
- observe and record lifestyles of occupants.
- examine and record physical condition of the units and its reaction to potential condensation producing conditions.

6d) RURAL HOME ASSISTANCE PROGRAM - monitored data.

- unique circumstances of this program, location, servicing and occupant social position.

7) ANALYSIS AND SYNTHESIS OF PROBLEM.

- determine the cause(s) and extent of condensation problem in mobile homes.

7a) CLUES AND OBSERVATIONS.

- as identified by literature and confirmed and/or observed in field investigation.
- extent of condensation problems and correlations to lifestyles of occupants, environmental conditions and physical condition and quality of dwelling units.

7b) HYPOTHESIS.

- identify probable causes.

7c) CAUSES.

- identify and explain the conditions which resulted in unacceptable degree of condensation.

8) REMEDIAL MEASURES.

- strategies, techniques and suggestions to minimize condensation problem in mobile homes.

9) REDUCING MOISTURE GENERATION.

- to lower indoor relative humidity.
- decrease potential for condensation.

9a) BUILDING MATERIALS.

- ability of building materials to absorb and emit water vapour.
- drying rate of new building materials.

9b) ENVIRONMENTAL.

- moisture laden ambient air.
- evaporation of ground moisture.
- rain penetration through the building enclosure.

9c) OCCUPANT LIFESTYLES.

- minimizing moisture production from occupant activities.

10) BUILDING ENCLOSURE.

- ability to resist rain penetration.
- ability to resist formation of condensation.

10a) THERMAL BRIDGING.
- decrease cold interior surfaces.

10b) AIR-VAPOUR RETARDANT SYSTEM.
- resisting the flow of air and vapour through the building enclosure.

11) VENTILATION.

- using drier winter air to lower indoor moisture levels.

11a) NATURAL AIR LEAKAGE.
- rate, effectiveness and dependability of natural air leakage into the building as a technique to control indoor humidity level.

11b) STACK EFFECT.
- rate, effectiveness and dependability of stack forces in mobile homes as a means of reducing indoor relative humidity.
- effects of raising the neutral pressure plane.

11c) FORCED CONVECTION.
- mechanical exhaust of moisture laden indoor air.
- control, noise level, maintenance and operational cost.
- cost and effectiveness of heat recovery ventilators.

12) DEHUMIDIFICATION.

- reducing indoor water vapour without venting.

12A) CHEMICAL.
- cost, effectiveness and appropriateness for mobile homes.

12b) MECHANICAL.
- cost, effectiveness and appropriateness for mobile homes.
- heat pump and heat recovery potential.

13) PREVENTIVE DESIGN.

- suggestions for new construction to mitigate effects and occurrence of condensation.
- controls and integration with furnace.

14) BUILDING ENCLOSURE.

- air-vapour retardant system.
- venting concealed spaces.

15) VENTILATION.

- techniques and potential for venting indoor air.

16) OCCUPANT LIFESTYLE.

- modifications and its effectiveness potential.

17) MAINTENANCE.

- regular maintenance of the building enclosure and mechanical system to maintain optimum design performance.

18) SUGGESTIONS FOR FUTURE RESEARCH.

- potential techniques for solving the condensation problem in mobile homes which need trial and monitoring.

19) CONCLUSIONS.

- assessment of this study and the remedial measures to mitigate the effects and occurrence of condensation in mobile homes.

APPENDIX B

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Architect

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Office (403) 270-3317
Home 288-0871

SURVEY QUESTIONNAIRE

"INVESTIGATION OF CONDENSATION IN MANUFACTURED HOUSING"

1) Owner's name (optional): ______
Address: ______
______ Telephone Number: ______

2) Location of house: [] EDMONTON, which mobile home park? ______
[] within 20 miles from city limits. Direction? ______
[] 20 to 50 miles, further ______ miles. Direction? ______

3) Who is the MANUFACTURER of your home? [] Regency (General),
[] Triple E (ALMA), [] others ______

4) How OLD is your home? [] before 1984,
40% [] 3 - 5 years,
56% [] 6 - 10 years, [] others 4%

5) What SIZE is your home? [] single 62% sq.ft. [] double 34% sq.ft. [] others ______

98% 14% 82%
6) Is your foundation fully skirted? [] YES/NO [], If yes, is it sealed? [] or, vented []

66% 32%
7) What type of ROOF shape? [] FLAT, [] PITCHED, [] CURVED, [] others ______

8) Insulation R - VALUE or inches of insulation on: ROOF ______, WALLS ______, FLOORS ______

98% 12%
9) WINDOWS are made of: [] Aluminum, [] Vinyl, [] Wood, [] Others ______

92% 44% (bay windows)
10) Number of PANES on WINDOW: [] single, [] double individual sliding, [] thermopane, [] triple

10% 56% 42% 40%
11) Have you added STORM windows? [] YES/NO [], Wrap PLASTIC around windows? [] YES/NO []

88% 18% 2%
12) Is your DOOR(S) made of: [] Wood, [] Insulated metal, [] Plastic, [] others ______

90% 4% 28% 58%
13) Do you have STORM doors? [] YES/NO []. Air lock VESTIBULE (enclosed porch)? [] YES/NO []

16% have a humidifier-setting range from 30% to 50%
14) If you have a RELATIVE HUMIDITY metre, what is the average winter reading? ______%

15) Do you use the furnace humidifier? [] YES/NO [], set at RELATIVE HUMIDITY of ______%

26% 58% (mostly small misters)
16) Do you use a portable humidifier? [] YES/NO [], gallons of water typically used per day ______

17) How many people live in this house? Number of ADULTS ____, Number of CHILDREN ____.
Number of CATS ____, DOGS ____, others ______
Size of AQUARIUM ______.

34%-12 or more plants 34%-6-11 plants 16%-fewer than 5 plants
18) How many house PLANTS do you have? 3" or smaller pots ____, 4" - 12" pots ____, larger ____

19) At what TEMPERATURE do you keep the house? ______ C/ F, Drop temp. at night? 56% day? ____
greater than 73 F - 8% 68 F - 24%
72 F - 26% less than 67 F - 4%
70 F - 34%

.../2

20) Do you feel STATIC electricity when touching objects and people? 16% [] often, 38% [] rarely, 42% [] never

21) Upon waking, do your THROAT or NOSE feel: 58% [] dry, 8% [] scratchy, 4% [] sore, [] others ________

22) Does your home feel STUFFY? 18% [] often, 52% [] rarely, 26% [] never.

23) Do you feel DRAFTS around: 66% [] doors, 60% [] windows, 42% [] electrical outlets, [] others ________

24) Are there any COLD SPOTS inside your house? Where? Master bedroom-38% Living room-16% Bathroom-18% Back door-12%

25) Have your DOORS ever FROZEN SHUT? 38% [] YES/NO 48% [], WINDOWS? 40% [] YES/NO 36% [], Often? ________

26) Have you notice any of the following in your house?

	CONDENSATION	FROST	MILDEW	STAINS DUE TO CONDENSATION
WINDOW FRAME	54%	52%	2%	18%
WINDOW GLASS	80%	52%		8%
DOORS	32%	20%		
DOOR FRAME	4%	10%		2%
DOOR KNOBS/HINGES	4%	6%		
WALLS	14%	10%	12%	20%
CEILINGS	46%	6%	12%	74%
FLOORS	8%		4%	
any CORNERS	10%	4%	4%	2%
TOILET TANKS	8%	4%		
WATER PIPES				

27) Is you DRYER VENTED to the crawl space? 10% [] YES/NO 4% [], or to crawl space and out? 76% [] YES/NO 6% []

28) Does your BATHROOM FAN turn on with the LIGHTS? 28% [] YES/NO 54% [], Of those that responded Yes 14% have disconnected the fan.

29) If separate switch for bathroom fan, do you use it: 24% [] always, 28% [] sometimes, 12% [] rarely, 6% [] never

29) Is your KITCHEN EXHAUST FAN vented to outside? 40% [] YES/NO 26% [], 12% [] used always, 26% [] sometimes, 34%-recirculating

30) Do you know what PRESSURE VENTS are for? 18% [] YES/NO 58% [].

31) Does your house have PRESSURE VENTS? 40% [] YES/NO 40% [], are they covered? 8% [] YES/NO 24% []

32) If you have CONDENSATION, FROST, MILDEW, or STAINS caused by condensation in your house, would you be willing to have someone look at it? [] YES/NO [], [] Days, [] Evng. [] Weekends

If YES, get their NAME: ________

ADDRESS: ________

Thank you for your help! ________ TELEPHONE: ________

N.L.C. - B.N.C.
3 3286 08906412 1